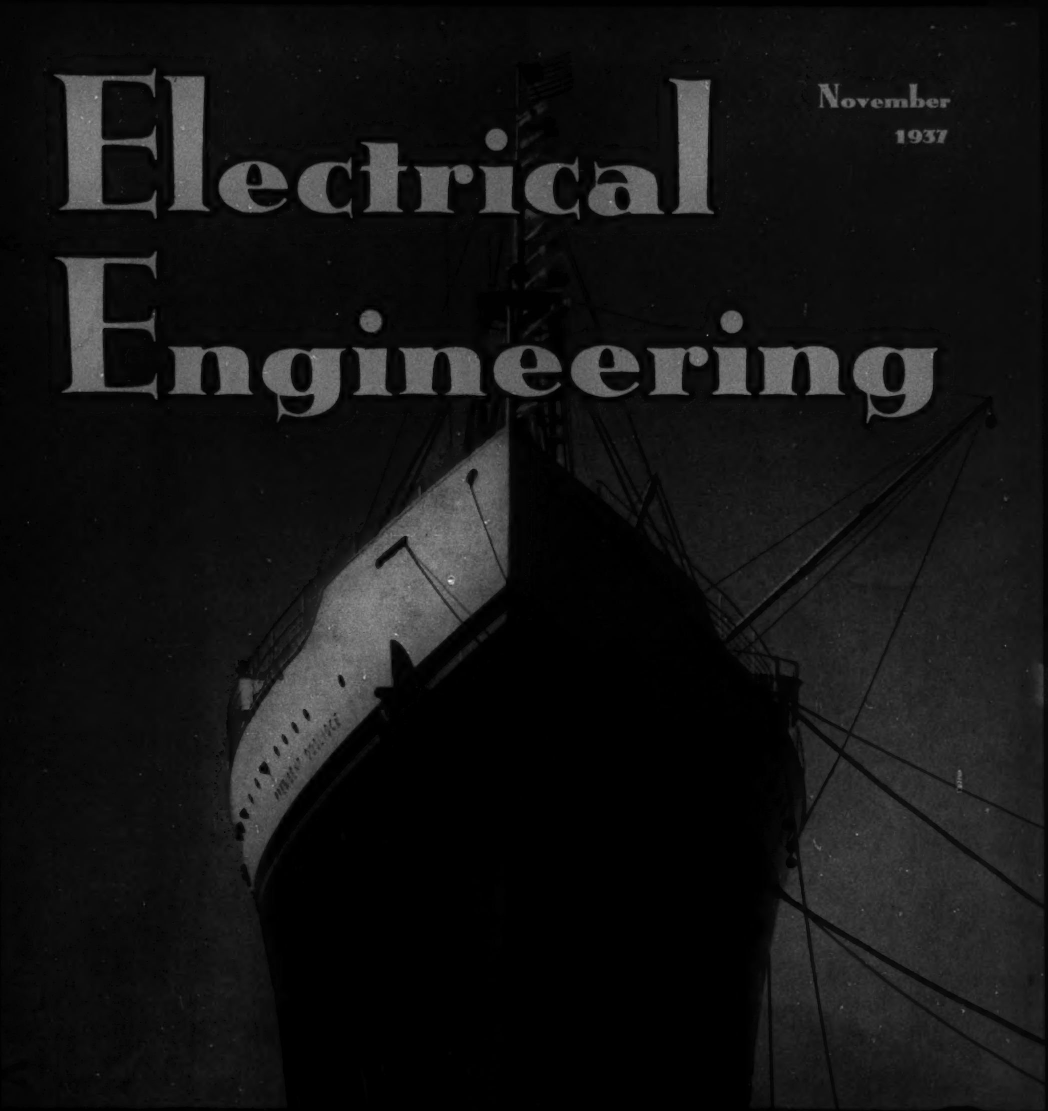
Electrical Engineering

November
1937



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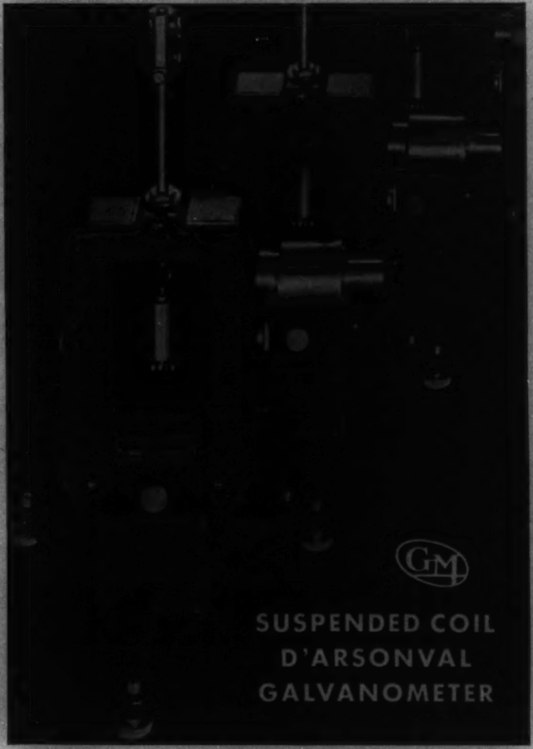

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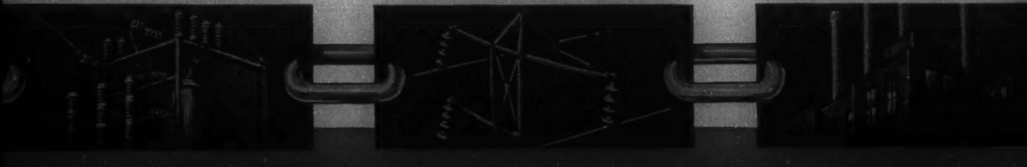

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Electrical Engineering

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VOLUME 56 NUMBER 11

Published Monthly by the

American Institute of Electrical Engineers

(Founded 1884)

W. H. Harrison, President

H. H. Henline, National Secretary
G. Ross Henninger, Editor
Floyd A. Lewis, Associate Editor
C. A. Graef, Advertising Manager

Publication Committee—I. Melville Stein, *chairman* J. W. Barker O. W. Eshbach H. H. Henline L. W. W. Morrow A. G. Oehler H. S. Osborne H. S. Phelps D. M. Simmons M. W. Smith W. H. Timbie

Entered as second class matter at the Post Office, Easton, Pa., April 20, 1932, under the Act of Congress March 3, 1879. Accepted for mailing at special postage rates provided for in Section 1103, Act of October 3, 1917, authorized on August 3, 1918. ¶ Publication Office: 20th & Northampton Streets, Easton, Pa. Editorial and Advertising Offices at the headquarters of the Institute, 33 West 39th Street, New York

The Cover

The completely electrified liner, S.S. "President Coolidge," powered by 2 13,250-horsepower 133-rpm synchronous motors each supplied from an individual turbogenerator set

Westinghouse Photo

High Lights

D-C Transformers. Various methods have been proposed for transforming voltage on d-c systems without using a motor-generator set. Although little practical use has been made of the device, the d-c transformer using grid-controlled mercury-arc rectifiers for commutating the direct current is one of the more promising of the systems thus far devised. The general theory of d-c transformers is discussed in a paper in this issue, and 2 new types of d-c transformers using grid-controlled mercury-arc rectifiers are described (*pages 1372–8*).

Grand Coulee Dam. Irrigating more than a million acres of land is one of the functions of the dam being built as part of the Columbia Basin project in the State of Washington. Pumps motor-driven by power generated at the dam will draw water from the river for distribution through hundreds of miles of canals; millions of kilowatt-hours of firm power will be produced annually. Construction of the dam is being accompanied by new accomplishments and records (*pages 1339–45*).

ECPD Annual Meeting. At the fifth annual meeting of Engineers' Council for Professional Development, additional engineering curricula were accredited, making a total of 442 curricula now so recognized in 127 educational institutions. Reports of committees and election of officers constituted the other principal items of business (*pages 1416–19*).

Correction. In the article "Engineering Income and Earnings, 1929–34," published in ELECTRICAL ENGINEERING for September 1937, the second sentence in the second paragraph under the heading "Earned Annual Income," page 1092, should read "Some 479 reported incomes less than $800 per year, while 295 earned more than $19,000 a year."

New Committee Chairmen. As usual, the newly appointed chairmen of AIEE committees are being introduced to the Institute membership through the "Personal Items" section. Items on the first group of chairmen were published in the October issue; items on the remainder are included in this issue (*pages 1424–6*).

Short Circuits. Water-wheel generators that are without damper windings and connected to a capacitive load such as an open transmission line can produce abnormally high voltages during unsymmetrical short circuits because of resonance or near resonance of the capacitance of the load and the reactance of the machine (*pages 1385–95*).

Load Loci. The method of circular loci may be applied to the solution of a circuit containing 2 transformers operating in parallel. The variation of current in either transformer or the ratio of the 2 currents is said to be obtainable as a function of the load impedance or the ratio of transformation without much involved computation (*pages 1379–84*).

Important developments in publication policy and procedure just approved by the board of directors, affecting both ELECTRICAL ENGINEERING and the TRANSACTIONS, are outlined on *page 1409* by Chairman I. Melville Stein of the AIEE publication committee.

Noise in Small Motors. Careless or inaccurate manufacturing methods sometimes are responsible for flaws such as uneven air gaps, loose bearings, or loose rotor bars, which contribute to noisy operation of small electric motors. Some of this noise can be minimized by proper design procedure (*pages 1359–67*).

Akron District Meeting. A strong and well received industrial flavor characterized the busy program of the recent Middle Eastern District Meeting. Of the 464 persons included on the registration list, approximately a third were students. A comprehensive report of activities will be found in this issue, beginning on *page 1410*.

Engineers' Income. Data derived from reports of 52,589 engineers tend to show that engineers engaged in technical work reach their maximum earning capacity later than those in nonengineering endeavors, but that this disadvantage is offset after a certain age (*pages 1353–8*).

Insulation Research. Principal advances in insulation research made during the past year were summarized in the report of the chairman of the committee on electrical insulation of National Research Council, presented during the 10th annual meeting of that body (*pages 1346–52*).

NRC Subcommittee Meets. At the recent annual meeting of the American Chemical Society held at Rochester, N. Y., the chemistry subcommittee of the National Research Council insulation committee held a symposium on insulation materials (*page 1420*).

Winter Convention. A "general" session has been scheduled tentatively on the program of the Institute's 1938 winter convention to be held January 24–28 in New York, N. Y. Preliminary plans for the convention are now under way (*page 1415*).

Nominations for Offices. For the guidance of the national nominating committee, suggestions for nominations for election to AIEE offices in 1938 are invited from the Institute membership (*page 1415*).

Letters to the Editor. Engineering education and democracy, and synchronous motor effects on induction machines are the subjects discussed in the "Letters" columns of this issue (*pages 1422–3*).

New AIEE Section. A new Institute Section recently was organized at Wichita, Kans. This increases the total number of AIEE Sections to 63 (*page 1414*).

Transformer Reactance. A mathematical formula for computing the reactance of the interleaved component of transformers has been derived (*pages 1368–71*).

DISCUSSIONS

Appearing in this issue are discussions of the following papers:

Education

A Suggested Course on Industrial Economics and Business Methods—Hellmund 1396

Per-Unit Quantities—Travis 1399

Fundamental Concepts of Synchronous Machine Reactances—Prentice 1400

Instruments and Measurements

A New Magnetic Flux Meter—Smith 1400

A New High-Speed Cathode-Ray Oscillograph—Kuehni and Ramo 1401

Sixty-Cycle Calibration of the 50-Centimeter Sphere Gap—Sprague and Gold 1405

Insulation Co-ordination

Basic Impulse Insulation Levels—EEI-NEMA Joint Committee Report 1405

Insulation Strength of Transformers—AIEE Subcommittee Report 1406

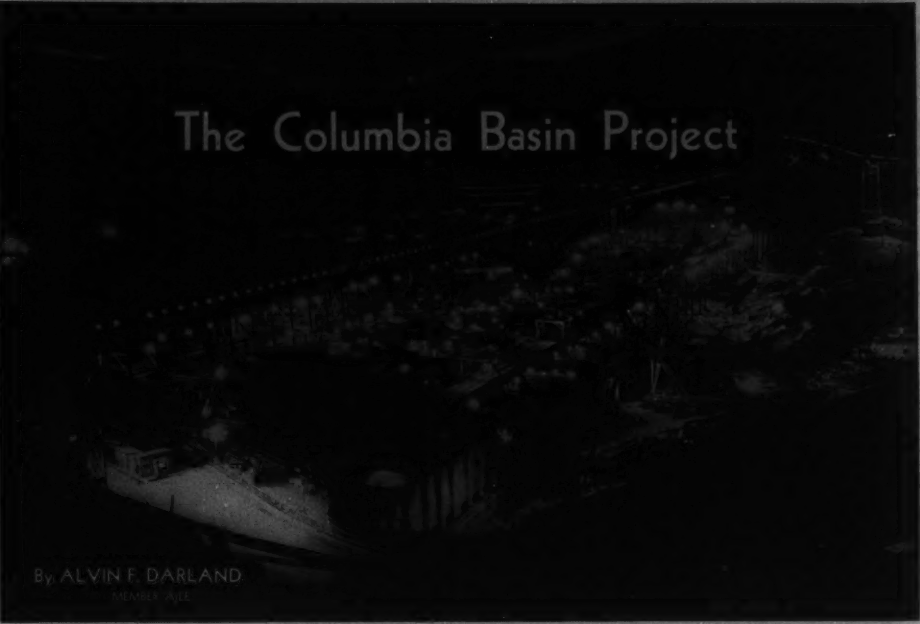
Application of Arresters and the Selection of Insulation Levels—Foote and North 1407

Insulation Co-ordination—Sporn and Gross . . 1407

Application of Spill Gaps and Selection of Insulation Levels—Melvin and Pierce 1408

Statements and opinions given in articles and papers appearing in ELECTRICAL ENGINEERING are the expressions of contributors, for which the Institute assumes no responsibility. Correspondence is invited on all controversial matters. ¶ Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶ Address changes must be received by the fifteenth of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ ELECTRICAL ENGINEERING is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London). ¶ Copyright 1937 by the American Institute of Electrical Engineers. Number of copies this issue—21,700.

The Columbia Basin Project



By ALVIN F. DARLAND
MEMBER AIEE

Grand Coulee Dam, now under construction on the Columbia River in the State of Washington, will create a 150-mile lake from which irrigation water for more than a million acres of land will be pumped by part of the power to be generated at the dam. This article describes the purposes of the project, which will not be completed in its entirety for half a century, and the present status of construction of the dam.

NEAR THE CENTRAL PART of the State of Washington is a pear-shaped body of semiarid land, approximately 85 miles long and 60 miles wide, containing $1^1/_4$ million acres of highly fertile soil, having a long growing season and a moderate climate, but without sufficient rainfall to support agricultural activities. This land, now largely covered with a determined growth of sagebrush and tumbleweed, was settled a generation ago by dry-land farmers who attempted to grow grain. Only a few relatively small areas have succeeded in maintaining anything approaching a successful farming venture. In those areas the key to success is water, available by pumping from a limited subterranean supply or an adjoining lake, or by enough rainfall to enable the harvest of an occasional crop.

Fifty miles to the north of the northern end of the irrigable area, and bordering its full length on the west, the Columbia River flows through a granite and basalt gorge from 300 to 1,500 feet below the level of the parched lands adjoining. The Columbia is the second largest river in the United States in the quantity of runoff, and the largest on the American continent in potential water power. Strangely enough, the Columbia at one time, diverted by a glacier choking its ancient gorge, was forced to carve from basalt rock a new channel some 50 miles long, from 2 to 5 miles wide, and from 600 to 1,000 feet deep, now known as the Grand Coulee. At the lower end of the Grand Coulee the diverted Columbia spread over the lands where the subsequent farming efforts failed because of the lack of water, and these lands today are known as the Columbia Basin. The river returned to its original channel after the glacial barrier melted, leaving the floor of the Grand Coulee 600 feet high and dry above its own restored level, and quitting at the same time its great lake-like channels in the Columbia Basin.

Preparation of Plans

Two plans proposed for the irrigation of the Columbia Basin were: first, gravity flow from the Clark Fork of the river by way of a long aqueduct; and second, damming the

---

Essential substance of an address presented at Coulee Dam, Wash., on September 3, 1937, on the occasion of an all-day inspection trip during the AIEE Pacific Coast convention.

ALVIN F. DARLAND is a native of Tacoma, Wash., and received the degree of bachelor of science in electrical engineering from the University of Washington in 1914. In 1923 he became superintendent of electrical construction and design in the public utilities department of the City of Tacoma, and was in responsible charge of the design and construction of 2 hydroelectric plants built by the city. Since 1935 he has been field engineer with the United States Bureau of Reclamation at Coulee Dam, Wash.

river near the head of the Grand Coulee to form a lake back of the dam, and pumping water from this lake into the Grand Coulee, whence it could flow by gravity to the land.

The United States Engineers, acting under authority of Congress, in 1932 submitted a report of a thorough study of these plans as one phase of the report on a comprehensive plan for the economic development of the river for power, irrigation, and navigation, from its crossing of the international boundary between Canada and the United States to its mouth at the Pacific Ocean, a river distance of 750 miles, through which there is a difference in elevation of the river of 1,300 feet. This report recommended the building of the Grand Coulee Dam as the key structure to the development of the power of the Columbia River, and the irrigation of the Columbia Basin by pumping from the lake formed by the dam. The ultimate building of 10 hydroelectric projects on the river having an aggregate capacity of 10,000,000 prime horsepower was recommended. Of these, the Rock Island Dam and power plant already have been built by private capital, while the Grand Coulee and Bonneville dams, the headwater and tidewater projects, are now under construction by the United States Government.

Outstanding attributes of the dam at Grand Coulee were cited as the doubling of the low-water flow of the river, an increase of from 50 to 100 per cent in the output of downstream power developments at low water because of the great storage afforded by the dam, and a reduction (from 635 feet to 295 feet) in the pumping lift necessary to divert water through the Grand Coulee to the Columbia Basin lands. The building of the dam was authorized by President Franklin D. Roosevelt in the fall of 1933 as a public works project, and work was started shortly thereafter under the direction of the United States Bureau of Reclamation; plans for the project previously had been prepared by the Bureau, following investigations and studies extending over a period of years.

Plan of Development

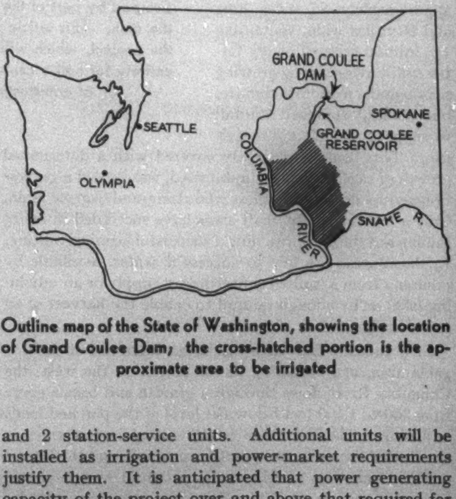
Fundamentally, the plan of development of the Columbia Basin project consists of: a dam across the Columbia River at the head of the Grand Coulee; 2 power plants adjacent to the dam utilizing the hydraulic head created thereby; a pumping plant to lift water from the lake created by the dam to a reservoir approximately 23 miles long, to be developed in the Grand Coulee by the construction of 2 dams, each about 90 feet high and crossing relatively narrow sections of the floor of the coulee; and a distribution system to convey the water from the reservoir to the 1,200,000 acres of land in the Columbia Basin that are to be irrigated.

The dam and power plant are estimated to cost $179,000,000 and to have an annual output capacity of 8,100,000,000 kilowatt-hours of firm power and 5,000,000,000 kilowatt-hours of secondary power. The sale of this power is expected to repay to the United States Government the cost of the dam and power plant, and half the cost of the irrigation system. Irrigation, including the pumping plant, will cost $198,000,000 and will be repaid, half by the revenue surplus from the sale of power, and half by the settlers of the land. The total annual cost to the farmer for the contemplated irrigation is now estimated to be about $5 per acre.

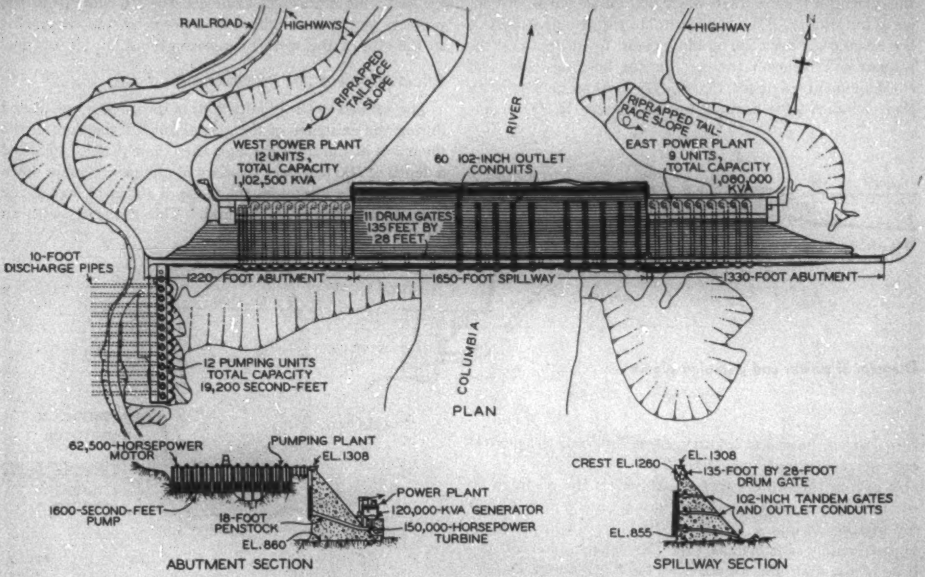
Dam and Power Plant

Grand Coulee Dam is being constructed upon the granite floor and abutments of the river gorge within a mile downstream from the point where the river was forced to make its glacial detour through the Grand Coulee. The structure, a straight gravity-type dam, will rise 550 feet above the lowest bedrock, will be approximately 4,300 feet long and 500 feet thick at the base, and will raise the river 335 feet, creating a lake 150 miles long reaching the Canadian border and providing 5,000,000 acre-feet of useful storage in the upper 80 feet of the reservoir. The average flow of the river is 109,000 second-feet at the dam site, but during an exceptionally high flow in 1894 is estimated to have reached 725,000 second-feet. A spillway 1,650 feet long with a capacity of 1,000,000 second-feet, and designed to dissipate without damage to the structure 30,000,000 horsepower of hydraulic energy, will be provided in the channel section of the dam. For the construction of the dam and power houses, 11¼ million cubic yards of concrete will be required.

A power plant having 18 120,000-kva main generating units and 3 7,500-kva station-service units is contemplated for the ultimate development, 9 main generating units to be in a power house to be constructed adjacent to the dam at its easterly downstream face, and the rest to be in a similar power house at the west end of the dam. The initial installation will consist of 3 main generating units and 2 station-service units. Additional units will be installed as irrigation and power-market requirements justify them. It is anticipated that power generating capacity of the project over and above that required for pumping of irrigation water will be absorbed within a 15-



Outline map of the State of Washington, showing the location of Grand Coulee Dam; the cross-hatched portion is the approximate area to be irrigated


RAILROAD
HIGHWAYS
RIPRAPPED TAILRACE SLOPE
WEST POWER PLANT 12 UNITS, TOTAL CAPACITY 1,102,500 KVA
RIVER
60 102-INCH OUTLET CONDUITS
HIGHWAY
N
RIPRAPPED TAILRACE SLOPE
EAST POWER PLANT 9 UNITS, TOTAL CAPACITY 1,080,000 KVA
11 DRUM GATES 135 FEET BY 28 FEET
10-FOOT DISCHARGE PIPES
1220-FOOT ABUTMENT
1650-FOOT SPILLWAY
1330-FOOT ABUTMENT
COLUMBIA
12 PUMPING UNITS TOTAL CAPACITY 19,200 SECOND-FEET
PLAN
62,500-HORSEPOWER MOTOR
PUMPING PLANT
EL. 1308
POWER PLANT
120,000-KVA GENERATOR
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CREST EL. 1260
EL. 1308
135-FOOT BY 28-FOOT DRUM GATE
102-INCH TANDEM GATES AND OUTLET CONDUITS
EL. 855
SPILLWAY SECTION

Grand Coulee Dam and appurtenant works

year period after completion of the dam and initial power development, but the development of the irrigation phase of the project is expected to continue for a much longer period.

Irrigation System

The pumping plant, which will lift the irrigation water from the lake to the reservoir in the Grand Coulee, will be constructed on a granite bedrock shelf upstream from the west end of the dam. The plant will have a rated capacity of 16,000 second-feet of water, and an installed capacity of 19,200 second-feet in 12 pumping units. Each pump will be rated at 1,600 second-feet and will be driven by a 62,500-horsepower motor, 2 such pumping units to be operated by the output of one main generating unit at the west power plant. The irrigation water diversion will amount to slightly more than a seventh of the average flow of the river, and will require the power output of 5 main generating units totaling 600,000 kva for pumping. The flood stage of the river is during the irrigation season, a fact of importance to this project.

Water from the pumping plant will be conducted through penstocks to a canal, which will connect with the irrigation reservoir in the Grand Coulee. Two relatively small dams will be constructed to close the 2 ends of the upper 23 miles of the Grand Coulee, so that water may be stored to a depth of about 70 feet and in a useful amount of 339,000 acre-feet above the elevation of the outlet to the distribution system.

A main canal from the southerly end of the irrigation reservoir at a point 11 miles farther south, will branch into a main east canal and a main west canal, the former to be 156 miles long and the latter 101 miles long. These 2 canals practically will encompass the irrigable lands of the basin. A system of lateral and distribution canals will finally convey water to 40-acre units of the project. During the irrigation season, it is estimated that an average of 40 inches of water can be supplied to the land, whereas the mean annual precipitation for the area is but 8.2 inches, and the rainfall during the irrigation season is only 3.6 inches.

Construction

During somewhat more than $3^{1}/_{2}$ years since the fall of 1933, work accomplished on the project represents a cost equal to approximately half the expenditure necessary to construct the dam (not including power development). The base of the dam has been built out from the west abutment to the original west bank of the river, and within this portion of the dam have been left multiple channels through which the river now flows while the building of the dam from the east abutment proceeds out across the old channel of the river to join that portion of the structure on the west side of the stream. This work has necessitated the building of 2 systems of cofferdams, the excavation of earth overburden amounting to 20,000,000 cubic yards, foundation rock excavation of 1,000,000 cubic yards, and the placing of more than 3,900,000 cubic yards of concrete to October 1937. Incidental to the principal work of the project has been the building of the towns, both on the project and adjacent thereto, for the housing, care, and entertainment of more than 6,000 workmen, who with their families have brought approximately 15,000 people to a barren, homeless country, 90 miles from the nearest commercial center (Spokane).

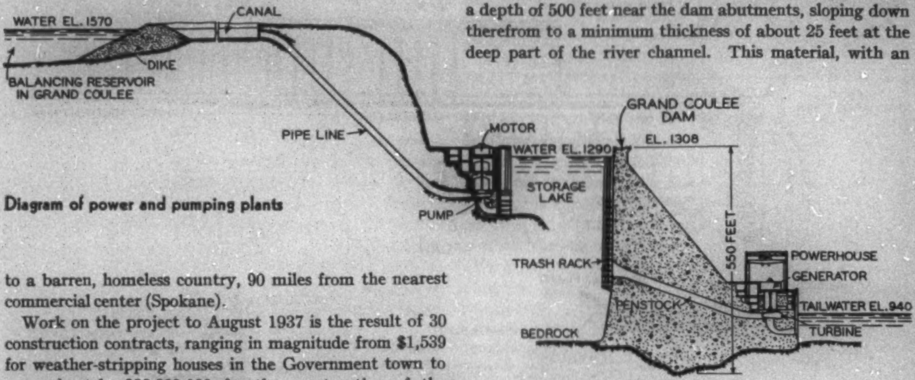

Diagram of power and pumping plants

Work on the project to August 1937 is the result of 30 construction contracts, ranging in magnitude from $1,539 for weather-stripping houses in the Government town to approximately $38,800,000 for the construction of the base of the dam and foundations for the 2 power houses. This latter, the principal contract of the project and the only one not yet completed, is held by the Mason-Walsh-Atkinson-Kier Company, a company organized by 3 previously independent contracting firms for the purpose of providing financing and equipment adequate to conduct operations on the large scale necessary at Grand Coulee Dam. In addition to the construction contracts, many others have been made for construction materials, the Government furnishing materials and equipment that become a permanent part of the dam and power plants.

The Mason-Walsh-Atkinson-Kier Company is within a few months of the completion of work included under its contract, which comprises briefly the building of the electrically heated Mason City, the contractor's town; most of the excavation required for the dam and power houses; the diversion of the river; and the manufacture and placing of about 4,500,000 cubic yards of concrete, which represents about 40 per cent of the concrete required for the completed dam.

Mason City at present has a population of 300 families and 1,200 single men in semipermanent houses and dormitories, and a population of 400 men in tents. The homes and dormitories, general store, recreation hall, hotel, theater, messhalls, and company office buildings are all electrically heated, comprising a connected electrical load of 8,500 kw, all of which is active during the cold-weather months. When this condition occurs, however, weather conditions are so severe that the electrical load from construction activities is greatly reduced, and an almost uniform power demand results. Peak power demand of the project has been 14,000 kw. Power is supplied by the Washington Water Power Company at a 110-kv switching station in Coulee City, 30 miles from the project, and is transmitted therefrom by the contractor to the site of the work over a single-circuit 110-kv line.

Excavation for the Foundation

The silt bed on the granite floor of the river gorge, placed during the existence of the glacial lake at the time of the diversion of the river through the Grand Coulee, reached a depth of 500 feet near the dam abutments, sloping down therefrom to a minimum thickness of about 25 feet at the deep part of the river channel. This material, with an occasional glacial deposit of sand and gravel, was removed by a battery of electrically operated power shovels, dumping into trucks and tractor-drawn buggies which ranged in capacity from 12 to 30 cubic yards; these in turn dumped onto a system of belt conveyers, likewise electrically operated, reaching to a canyon a mile away from the dam site and having a daily capacity of 48,000 cubic yards of excavated material. Operation of these belts required 5,000 horsepower of electric energy.

Bedrock excavation necessary to remove weathered rock and shape the granite floor and abutments in a manner suitable for foundation purposes has required excavation of about 1,000,000 cubic yards of rock over an area of 38 acres. Blasting of bedrock was permitted only with light charges of dynamite in relatively shallow, closely spaced holes, in order to minimize disturbance to sound bedrock uncovered by the removal of weathered rock. The excavated rock was hauled by trucks since the belt conveyers were unsuited to this type of material, and

(Right). A view of the dam, looking west. High- and low-level construction trestles each have a battery of 5 traveling cranes. The suspension bridge carries a belt conveyer that delivers sand and gravel to a concrete-mixing plant at the west end, and a pipe line that delivers cement to a mixing plant at the east end. A 50,000-barrel cement storage and blending plant may be seen at the upper left, where 60 carloads of cement are unloaded daily and blown by air through pipe lines to the mixing plants. The completed dam will reach the elevation of the highway in the background

much of it used in riprapping the tailrace and river slopes downstream from the dam. The granite floor of the dam is generally quite level, except for 3 secondary gorges across its floor that reach depths of 100 feet below the general level. The quality of the final foundation rock ranges from good to excellent granite, superior in all cases to the best concrete that can be produced. A curtain of cement grout to seal the contraction and structural joints in the bedrock will be injected in an approximately vertical plane parallel to the axis of the dam and under its upstream portion throughout the full length of the structure to depths as great as 300 feet, and with a thickness at right angles to the axis of about 100 feet.

Diversion of the River During Excavation

The excavation on both the east and west sides of the river was carried to bedrock elevations as much as 200 feet below the water surface of the river. Two cofferdams were built to enable this excavation. The first of these, constructed during the winter of 1934–35 on the west bank of the river, was a bow-shaped structure, about a half mile long, with a central section parallel to the river channel, and the wings cutting into the silt banks of the stream. This structure employed in its building 17,000 tons of interlocking steel piling, and attained a height of 100 feet, sufficient to safeguard operations for a river rise of 55 feet above the low-water flow of the stream. The second cofferdam was constructed during the fall of 1935 on the east side of the river, and was of a shape similar to the west cofferdam, but employed timber rather than steel piling and was built only to an elevation sufficient to withstand a river rise of 30 feet above low water. This structure was topped by the river as anticipated, and work within the east cofferdam was suspended during a period of 3 months in the summer of 1936. Both the west and east cofferdams were unusually tight and but little pumping because of leakage was necessary, a condition resulting from the adequate designs by the contractor and the generally tight nature of the silt deposits over the old lake bottom.

Following completion of bedrock excavation within the west cofferdam, construction of the dam and west power house was started in the fall of 1935. About 1,500,000 cubic yards of concrete has been placed in this portion of the structure. This section of the dam contains the temporary diversion channels through which to detour the river from its original channel, and was completed to a stage of construction necessary to enable opening of the west cofferdam to the river in November 1936. In the

A view of the dam, looking upstream (south). The Government camp, Coulee Dam, is on the right side of the river; the highway bridge leads to Mason City. The river is shown at about the stage of average flow meantime, construction had been started on the shore arms of the upstream and downstream main river cofferdams to close the river channel and enable its unwatering for construction purposes. These 2 structures were built of timber cribs rock filled and armored with a single row of interlocking steel piling driven to refusal. The cross-river cofferdams were joined to useful portions of the original west cofferdam, which portions were joined in turn to the upstream and downstream faces of the west section of the dam in such a manner that the diversion channels were west of the junction points. This arrangement exposed the east end of the west section of the dam within the enclosure formed by the main river cofferdams. Completion of these structures and the full diversion of the river through the west section of the dam were accomplished in December 1936. Removal of overburden and foundation-rock excavation had advanced from the east abutment within the area enclosed by the east cofferdam and concreting operations had been started prior to the diversion of the river. When the diversion was accomplished, and the old river channel unwatered, these operations successively advanced across the channel to meet the west section.

Improved Methods

The successful conduct of construction work on the huge scale demanded by the physical and economic factors at Grand Coulee Dam has naturally resulted in superlative accomplishments. Here during the excavation period, for instance, was the world's largest conveyer system; now there are in operation the largest concrete aggregate preparation plant, the largest concrete mixing plants, and the greatest assembly of concrete placing equipment ever on a single construction job. The acceleration of construction rates has been accompanied by the adoption of improved methods with more consistent and uniform results than heretofore have generally been achieved. An illustration of this is the high quality of the concrete going into the dam. The average compressive strength of 3,214 28-day test cylinders, 6 by 12 inches, taken at the mixing plants from mass concrete for the dam and dry screened to $1^1/_2$-inch maximum aggregate, was 5,545 pounds per square inch, with a very high uniformity factor. Mass concrete contains one barrel of cement per cubic yard. Concrete has been placed at a rate of 15,500 cubic yards per day and it seems probable that this record may be extended to 18,000 cubic yards per day before work is completed under the present contract.

Control of Slides

Unexpected difficulties have been experienced because of landslides of the lake-bed silt deposits from the granite side walls of the river gorge into the excavation area of the dam and power plants. Two major slides have occurred, one on the west side where about 1,000,000 cubic yards of material moved toward the power house and tailrace sites, and a second on the east side of the gorge, that moved into the forebay and dam excavation. The additional excavation occasioned by these slides amounted to 1,500,000 cubic yards of material and necessitated the construction in the west slide area of a drainage system and a rock barrier at the toe of the slide to a height of 120 feet above the level of bedrock, with a ballast blanket consisting of 225,000 cubic yards of gravel spread on the slopes of the slide above the barrier. A complete cure was necessary to prevent the slide moving into the tailrace and turbine discharge outlets of the power house.

The east slide was directly into the largest depression crossing the granite floor forming the foundation of the dam. Although movement of the slide subsequent to the construction of the dam could do no damage, about 500,000 cubic yards of slide material had to be removed to enable the complete excavation of the depression and the placement of concrete. Considerable additional excavation was avoided by the construction of a temporary barrier across a neck of the depression at a point just outside the upstream limit of the dam, to prevent further movement of the slide during the time required to fill this depression with concrete.

Before this land slide started, a concrete arch about 25 feet high, topped by a timber crib 15 feet high, had been constructed across the neck of the depression. As the slide became active, these structures were buried under the toe of the slide, which at this point was about 100 feet deep above bedrock. The slide was temporarily stabilized by the removal of the surcharge from its fan-shaped upper portion. A refrigeration plant of 80 tons capacity was rented and erected at a nearby site, and pipes through which brine could be circulated were driven into the slide. An earth-ice arch 100 feet long, from 20 to 25 feet thick, and from 42 to 50 feet deep was frozen directly over the concrete arch and timber crib submerged by the slide, and this composite structure of concrete, timber, and ice proved to be an adequate barrier to further movement of the slide and enabled the necessary excavation for the dam to be completed, and subsequent phases of the work to proceed without interruption. The dam was frozen in September 1936 and was abandoned in April 1937.

Plans for Completion of the Project

Plans and specifications are now being prepared in anticipation of a contract to provide for the completion of the dam and west power plant building, funds to continue with the construction program having been appropriated by Congress. If future appropriations are adequate to continue at the construction rate established for the work now accomplished, the dam could be completed and the initial power-plant installation ready for operation by 1941. Surveys are in progress in the irrigable area to enable the planning of the system of canals and aqueducts necessary to convey Columbia River water to the lands of the Columbia Basin. There is a growing and insistent demand for irrigated land, and it now appears likely that the 50-year period for combined irrigation construction and land settlement originally contemplated for this project may be materially shortened. The lands, when irrigated, will provide from 30,000 to 40,000 new farm homes and an equal number of homes forming urban communities of the project.

Recent Progress in Insulation Research

By J. B. WHITEHEAD
PAST PRESIDENT AIEE

Another in a series of annual reports presented by the chairman of National Research Council's committee on electrical insulation, this article summarizes some of the principal advances in research work on gaseous, liquid, and solid dielectrics during the past year. References are included to both fundamental scientific studies and practical research under service conditions.

RESEARCH in the field of dielectrics and insulation is broadly speaking of 2 general types. The first is that of fundamental scientific character in the fields of chemistry and physics. There is a constant flow of the results of studies of this type in the field of dielectrics, gaseous, liquid, and solid; and as related to their various properties, dielectric constant, electric conductivity, and breakdown. Intense interest attaches to the slow but steady unfolding of the picture of atomic and molecular structures, and of the phenomena associated with the movements therein of electric ions of various character. Unfortunately, however, it is not always possible, by reason of our inability to control the forces and extend the laws so discovered to large-scale conditions, to apply the results of this type of research to the construction and behavior of everyday insulation.

The second type of research is that in which effort is made to develop directly under the conditions of normal service improved materials and methods for insulation. Such efforts watch more or less distantly the progress of fundamental scientific research and are quick to grasp and try out on a practical plane any new discovery or suggestion. Thus, while they often have a cut-and-try character, and in this sometimes suffer criticism in comparison with more fundamental types of research, it nevertheless remains a fact that a large proportion of the advances that have been made in the improvement of electrical insulation have been through researches of this character.

Obviously both types of research are very much the concern of the committee on electrical insulation, of the National Research Council, and this review includes notices of the principal advances during the past year which have come to the writer's attention. It includes reference to a number of researches of the first type in which there is a definite interest as related to the problems of insulation, even though sometimes remote. On the other hand, the review makes no pretense of covering completely the large volume of important research of the first type which has appeared.

Gases

From the standpoint of insulation, first interest for gases attaches to conductivity and breakdown. Most of the new work during the year has been on breakdown in air. Some of it is purely practical in character, other continues the study of the process leading from initial ionization to self-supporting spark or arc discharge. This problem continues to hold the interest of both physicists and engineers; of the former because of the light thrown on gaseous structure and submolecular behavior; of the latter because of the obvious bearing on the mechanism of the spark and arc and of various types of protective equipment.

The use of the spark gap in its various forms as voltmeter is reviewed by W. M. Thornton.[1] Best methods and empirical formulas are suggested for needle gaps, sphere gaps, plane electrodes, the corona voltmeter, the attracted-disk electrometer, the ellipsoid voltmeter, the capacitance divider, etc. K. Potthoff[2] continues a series of papers developing the relationship between corona loss as measured on laboratory equipment and the losses which occur in overhead lines. Comparative results on the laboratory equipment, consisting of wire and coaxial cylinders, and those observed on 3-phase open lines show fairly good agreement. E. Horst[3] reports an extensive study of the time constant of capacitors. The time constant in general decreases with increasing voltage, and a wide range of values is found for commercial capacitors. This author believes that the residual phase difference in air capacitors is due principally to leakage over the insulating supports rather than to radiation and electrode surface phenomena.

Of more fundamental character are a number of studies on the breakdown of gaps of various lengths and under different conditions. R. Strigel[4] reports (from the Siemens laboratories) studies on the spark lag in a uniform field and in the field between points. From the same laboratories is a study by Von Engel and Steenbeck[5] on the rôle of the positive ions in a gas discharge. All of these papers discuss the mechanism of the setting up of preliminary and then final complete discharge, with particular reference to the influence of the space charges due to the more rapidly moving electrons and the sequence of happenings leading up to the avalanche of electrons. A clear picture is drawn of the growth of the electronic avalanche introducing as new element the electrostatic force

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Part of the annual report of the chairman of the committee on electrical insulation, division of engineering and industrial research, National Research Council, presented during the 10th annual meeting at New York, N. Y., November 4–5, 1937.

J. B. WHITEHEAD, professor of electrical engineering and, since 1919, dean of the school of engineering at The Johns Hopkins University, Baltimore, Md., has been a member of the faculty of that university since he was appointed associate professor of electrical engineering in 1904. He received his first degree in engineering from Johns Hopkins in 1893, and subsequently received those of bachelor of arts and doctor of philosophy. Doctor Whitehead was the founder of the Institute's Baltimore Section, and was its chairman for 19 years. A Life Member, he has served on many committees and on the board of directors, and was president during 1933–34. He is now a junior past president and a member of the committees on code of principles of professional conduct, Edison Medal, and Institute policy, and representative on the John Fritz Medal board of award and National Research Council, division of industrial and engineering research. He has been chairman of National Research Council's committee on electrical insulation since 1923.

[1] References listed at end of paper.

on the electron caused by space charge, and the setting up of an accelerating force greater than that caused by the external field. The necessity for such additional force is shown by measurements indicating very high ionic mobilities. A. Köhler[6] studies the impulse breakdown at pressures between 100 and 760 millimeters of mercury in uniform fields. He shows that for both alternating and impulse voltages down to 4 milliseconds duration, Paschen's law is confirmed down to 100 millimeters for dry air, but not for air containing moisture. The cathode-ray oscillograms clearly indicate a break in the descending voltage curve after breakdown, which is attributed to the passage from spark to glow discharge. E. Finkelmann[7] studies the breakdown of different gases at high pressures up to 20 atmospheres; in homogeneous fields in gaps up to 2 centimeters, and in coaxial cylinders in gaps up to 4 centimeters. The gases studied are oxygen, carbon dioxide, air, and hydrogen. The departures from Paschen's law already recognized for small gaps are also found for large gaps. They begin at higher voltages, the greater the gap; and for different gap lengths at approximately the same field intensity, the value of the latter varying with the gas. The departures are attributed to space charges and consequent electron emission from the cathode. On account of the smaller increase of breakdown voltage of oxygen, as compared with that of carbon dioxide, the latter is to be preferred as an insulator in high-voltage practice. H. Böcker[8] studies the well-known lowering of breakdown voltage at high frequencies. The commonly accepted cause is that at a certain critical frequency during a reversal of the electrode voltage, positive ions accumulate as space charge. A limitation of the space charge is set by the rate of diffusion. Starting from this condition, the author computes the density of space charge necessary to account for the actual field distortion and derives a formula for the lowering of voltage at higher frequencies. This formula is closely similar to that for the lowering of static continuous voltage as computed by Rogowski and Wallraff.[53] The decrease of breakdown voltage with frequency above the critical value so computed is in good agreement with the experimental results.

Outstanding contributions in this country to our knowledge of all forms of gaseous discharge are made by L. B. Loeb and co-workers.[9] In an admirable review of the mechanism of static spark discharge Loeb not only reports much work of himself and co-workers, but makes a comparative study of the significance of the results of others. The beginning of any type of discharge at ordinary air pressure is due to the collision of electrons with molecules and the liberation of further electrons, in accordance with Townsend's theory. The presence of electrons is necessary and there is always a sufficient number due to external causes to start matters. This is called by Loeb the primary process of ionization. The resulting current of itself does not usually lead to a spark, but as the applied field is increased the increase in current may become very rapid. An unstable condition results in which the current readjusts itself so as to become self-maintaining, that is, it changes to glow discharge, brush, spark, or arc. In order to reach this self-maintaining condition the ionization current must develop a mechanism by which new electrons are generated in sufficient number; that is, some new or secondary ionization process must arise. Loeb lists at least 5, and including very low pressure, 6 mechanisms of self-maintaining character by which spark discharge can occur. Among these are, in the gas itself, ions and atomic excitation by electron impact, ionization by positive-ion impact in the gas, photoelectric action in the gas, and at the cathode electron bombardment, positive-ion bombardment, photoelectric effects, and the so-called field currents, all leading to increased electron emission. Of special interest is the conclusion that under ordinary conditions ionization in a gas by positive-ion impact, as first suggested by Townsend, does not enter into the sparking equations. The most common secondary influences are the liberation of electrons at the cathode by positive-ion impact, and with photoelectric electron liberation at the cathode and in the gas. An influence of metastable atoms is noted in certain special cases, for example, low-pressure corona; also with sufficient initial ionization high local fields may be caused by space charge, leading directly to spark. The essential conclusion of Loeb's analysis is that there is no single definite secondary process which occurs universally in all discharge phenomena, but that depending on the particular circumstances, usually one or 2 of the secondary influences mentioned predominate to the exclusion of others. Other interesting experimental studies from the same laboratories, some of which are utilized in Loeb's analysis, are those of R. R. Wilson[10] on very short time lag in sparking, that of D. Q. Posin[11] on the Townsend coefficients, that of Cravath and Loeb[12] on the mechanism of the high velocity of the lightning discharge. In connection with the latter, one of the difficulties has been that the leader lightning stroke moves faster than any possible electronic velocity. "Calculations based on justified assumptions concerning the conditions known to exist in a lightning stroke show that if the field just ahead of the tip averages 10^6 volts per centimeter for about one centimeter, ionization by collision by the electrons already present in the gas before the stroke would be great enough to advance the tip at the observed rate. In this way a propagation of the leader stroke at a velocity many times higher than the velocity of the electrons can be attained."

Liquids

As is usual, work in this field is very voluminous. Liquids are more readily controlled, purified, and offer more uniform molecular structure than solids, and so offer themselves more readily for fundamental research. Entering as they do into many types of insulation, they also appeal to the research engineer.

To the engineer, the most interesting properties are dielectric strength and conductivity; to the physicist and chemist, dielectric constant is more important for the study of molecular structure. Theories of dielectric strength and breakdown take a wide range. The Schumann-Nikuradse theory of breakdown ties in the current-voltage characteristic in much the manner as now accepted for gases, and sees failure as an internal collision ionization phenomenon. Koppelmann and Gyemant invoke an electrode layer of high stress due to space charge acting on a layer of adsorbed gas, thus creating gas pockets or filaments leading to gaseous ionization and breakdown. Pure electric breakdown is apparently due to electronic collision ionization and is recognized only in the purest liquids. Thermal breakdown on the other hand, due to the liberation of gases by heating in impure liquids, is also evident in many cases. From the variety of conditions which are suggested in the work supporting these several theories it may be easily seen that the approach to pure electric breakdown occurs only under conditions in which the liquid and electrodes are most carefully purified, conditions which cannot be approached for large scale use. Breakdown in liquids prepared under the best manufacturing conditions is commonly of thermoelectric character, with gas evolution and gas breakdown as the final stage. The following brief notices of recent work in this field for the most part support this view. W. Bahre[13] reports a careful series of observations on the breakdown strength of liquid and solid benzol. The outstanding feature is the extreme elaboration, over a period of months, of methods of purification. Under the final test conditions breakdown strength of the liquid reached the high value of 1,870 kilovolts per centimeter and solid benzol 1,000 kilovolts per centimeter. In each case the peak value of a wave was the determining factor, indicating electric breakdown. The very smallest amounts of added impurities lowered the dielectric strength and increased the influence of the effective rather than the maximum value of voltage, indicating entrance of thermoelectric influence. Careful studies of the influence of drying and degassing supported in general the Koppelmann theory. Working in the same field, R. Bredner[14] studies toluol, chloric benzol, nitrobenzol, and benzol, as regards both dielectric strength and loss. Similar care was exercised for purification and similar evidence adduced that for toluol in this state, breakdown cannot be thermal in character. It is shown to be independent of the rapidity of voltage increase and independent of the pressure. On the other hand, the values for chloric benzol and nitrobenzol were much lower and gave evidence of thermoelectric failure, although breakdown was still independent of pressure. Here then is a case in which thermoelectric failure seems to take place without special reference to gas formation, thus indicating the Nikuradse type of breakdown. A. Walther and O. Tscheljustkino[54] conclude that the characteristic dependence of electric strength on pressure in liquids occurs only when the gas is in emulsified form. Liquids in which the gas is completely dissolved have electric strength independent of pressure.

Of special interest as related to the foregoing are 2 papers by E. Conradi[15,16] on the breakdown behavior of commercial insulating oils. He finds the following behavior: (*a*) As delivered, from 25 to 50 kilovolts per centimeter; (*b*) after filtration, from 75 to 125 kilovolts per centimeter; (*c*) 3 millimeters vacuum, 100 degrees centigrade, 12 hours, from 120 to 150 kilovolts per centimeter; (*d*) special filtration and 3 millimeters vacuum, 100 degrees centigrade, 12 hours, from 160 to 200 kilovolts per centimeter; (*e*) 3 millimeters vacuum, 240 degrees centigrade, and direct distillation, from 200 to 245 kilovolts per centimeter. Rotating a commercial oil in a circular channel between high-voltage electrodes, at a certain velocity dust and fiber particles are swept out and a breakdown stress of 150 kilovolts per centimeter is reached, an increase of upward of $33^{1}/_{3}$ per cent, and the spread of test points is reduced to 7 per cent or 8 per cent. Combined with a specially constructed electric filter, this method increased the low breakdown strength of badly deteriorated oil to 150 kilovolts per centimeter. Fibers and dust particles cause breakdown; thermal breakdown pertains to intermediate ranges of purification; and the pure electric breakdown enters only under extreme purification. Further interesting data are presented by F. M. Clark[17] on the properties of noninflammable synthetic insulating oils of the chlorinated diphenyl type. An advantage in favor of the synthetic liquids and insulation treated therewith of at least 20 per cent over corresponding mineral-oil values is claimed.

OXIDATION

Studies of the oxidation process in insulating liquids have also continued. A. Gemant[18] proposes a rapid and simple approximate method for relative oxidation rates, based on the decrease of volume of the gas over the oil in a closed vessel. The claim is that for the better oils the contribution of volatile products of oxidation may be neglected. J. F. Gillies and J. B. Black[19] reach the conclusion that dielectric strength and power factor of transformer oil are not affected in the early stages of oxidation, nor until heavier asphaltine products begin to be formed. Similar conclusion by different methods is reached by J. B. Whitehead and T. B. Jones[20] as reported at the present meeting of this committee. G. M. L. Sommerman[21] reports results of tests on 9 viscous mineral oils of various types and their mixtures with 8 rosins. Interesting correlations between physical and electrical properties, stability in oxidation, with the viscosity index and chemical composition are reported. J. B. Whitehead and F. E. Mauritz,[22] working with a single insulating oil of high quality, have shown important correlations between changes in electrical properties, and those of several oxidation products. P. J. Haringhuizen and D. A. Was[23] report welcome quantitative measurements of the catalytic action of metals on oils. The samples were treated for 1,000 hours at 90 degrees centigrade in the presence of thin layers of copper, lead, and tin. Copper formed the most sludge, lead next, and tin least. In two of the oils contact with tin gave less sludge formation than in a blank specimen, thus suggesting an antioxidizing value. Studies of the acid number indicate that the action of copper is at first the most rapid, but that after a time the acid number becomes constant while that caused by lead finally rises above those of both copper and tin, approaching a constant value of 7. It is suggested that catalytic action in all these cases is limited, due to the accumulation of protective products on the metals. T. Itoh and Y. Hyraki[24] report methods for the recovery of badly deteriorated oils by evacuation and distillation. Claim is made that the recovered oils were superior to the original oils, and that the volume recovered is better than 93 per cent.

Results by A. Lasarev and J. Raschektaev[25] conclude that the electric conductivity of oils polymerized by oxidation depends only on the mobilities of the ions and on changes in the macroscopic viscosity. The effect of increased temperature is to increase the decomposition of secondary associated complexes. It is stated that the Debye dipole theory adequately accounts for the temperature changes of the dielectric losses of those polymers and oxides examined, and other interesting suggestions are made.

GAS GENERATION

The generation and absorption of gas in insulating oils subjected to electric discharge has been studied by Nederbragt,[26] whose results show a wide variation in volume of gas liberated over a range of oils. Of special interest is the reduction of the amount of gas evolved by the addition of selected aromatic compounds. No general formula is proposed, but the author concludes that the volume of gas generated depends on the nature of the most volatile components of the oil, and that in general the gas evolved may be substantially reduced by small percentages of aromatics, more volatile than the oil itself. In these experiments the gasifying agency is merely the layer of ionized gas or vapor over the oil, the field being roughly parallel to the surface of the oil. The nature of the action is not suggested, and should be a promising problem for further study.

CONDUCTION

Studies of conductivity at high stress in insulating liquids are as follows: In experiments on carefully distilled toluene, E. B. Baker and H. A. Boltz[27] claim to have demonstrated the presence of thermionic emission at ordinary temperatures from cathodes in contact with dielectric liquids. The current-voltage relations found obey, in the upper range of field strength, a law which is interpreted as being a modification of the Schottky law in vacuum. Differences are found amongst curves for adsorbed oxygen and hydrogen on electrodes of several metals and explanations offered on the basis of variations in the work function of the metal. They contrast their results with the commonly accepted view that residual conduction in dielectric liquids is due to ions initially present, formed by some ionizing agent or electrolytic dissociation. An interesting feature of the results is that the slope of the current-voltage curve of the liquid becomes less steep in the upper range. The theory of secondary ionization, as described by Nikuradse, calls for log I increasing directly as the field whereas the Schottky law calls for a log I variation as the (field).$^{1/2}$

Closely related to the foregoing is the work of K. H. Reiss,[28] on ionization by intense ultraviolet radiation in highly refined liquids. The author concludes that the rise in the current-voltage characteristic of highly refined insulating liquids above the saturation value is not due to ionization by collision, as proposed by Nikuradse, nor to cold thermionic emission, as proposed by Baker and Boltz.[27] The chief experimental evidence against ionization by collision is in the observation of the increase of current over normal saturation and rising current regions, as between the nonirradiated and the irradiated conditions. The increase in conductivity due to the ionization by ultraviolet radiation was found to be constant up to 200 kilovolts per centimeter, that is, well above saturation. In other words, the large increase in the number of ions due to ultraviolet radiation did not cause any increase in the ionization by collision. Cold electron emission was eliminated by experiments with the electrode irradiated by ultraviolet radiation. A very small increase of current was noted at low field strengths, but for increasing voltage the increasing curve merged with the normal curve of the liquid. The increase of conductivity with stress is attributed by the author to the phenomenon discovered by Wien and Schiele of an increase of field strength in weak electrolytes, arising in dissociation at higher voltages. Particular support for this view is found in measurements on the mobilities of the ions which are found to be much lower than those of electrons involved in avalanche and secondary ionization processes. The author concludes that breakdown in insulating liquids at values below 400 kilovolts per centimeter can be caused only by the liberation of gas, thus supporting the Koppelmann view. Ionization phenomena in liquid hydrocarbons are also studied by C. Bialobjeski[29] utilizing X rays. He shows 3 kinds of ions, of which two are positive and the other negative. He makes studies of mobility and coefficients of recombination. Commenting upon Nikuradse's theory of the relation between the current-voltage characteristic of a liquid, and its approach to breakdown, Y. Toriyama and U. Shinohara[30] have measured the impulse breakdown voltage of distilled water and several aqueous solutions. In particular, they point to the case of a solution of NH_4OH, in which the breakdown voltage is greater than that for distilled water, although the conductivity of the solution is 7.5 times greater. They claim, therefore, no direct relation between the current-voltage characteristic and breakdown and that the latter is an electronic rather than an ionic conduction phenomenon.

Solids

Owing to the complexity and wide range of type of conduction processes in solids, and to the difficulty of securing strict uniformity in bulk, research in the field of solids, as directed to their properties as insulators, is still of a broadly general character. Nevertheless much progress has been made, some of it recently, and in certain classes of materials general correlations are to be found between chemical composition, physical properties, and electrical constants and behavior. Thus in the case of the glasses, one of the most baffling groups, certain constituents are now recognized as related to conductivity and dielectric loss. The particular way in which moisture remains in fibrous materials is recognized and certain methods of control have been developed. There has been much study of the molecular polar properties of liquids when passing into the solid state and some grouping of materials as to the polar variation of dielectric constant and dielectric loss. Studies of synthetic materials have been particularly successful in indicating wide changes in electrical properties associated with well recognized chemical variations. Examples of this are the thermoplastic rosin, poly-styrene, and the chlorinated diphenyl compounds. Similar studies have been made in the ceramic field, notably the steatite and rutile groups, the latter affording, when compounded with suitable binders, the possibility of a very wide range of value of dielectric constant. An excellent survey of some of these relationships has been presented during the year by W. Jackson.[31] In the experimental study of the dielectric strength of various types of solid materials, J. C. Dowell and C. M. Foust[32] present an important assembly of curves and data showing the impulse and 60-cycle breakdown voltages of various gaps, bushings, insulator strings, creepage paths in both liquid and solid materials. The data are presented in 33 sets of curves and 5 tables, and constitute a valuable reference source. An analytical study of the results of many workers on the breakdown of solids is given by S. Whitehead[33] in an effort to determine the figures for the breakdown strength inherent in the materials themselves. He attributed failure in practice (1) to the properties of the ambient medium, (2) to imperfections of macroscopic order in the solid material itself, (3) to the presence of foreign materials, moisture, etc. The present study looks away from these causes and analyzes the results of many workers for a determination of the limiting electric strength as determined by (*a*) thermal instability, (*b*) internal ionization, (*c*) ultimate electric strength. The author concludes that evidences of failure due to internal ionization are not very definite, and that the figures indicated for ultimate or pure electric strength, as studied by Rogowski and Von Hippel, are far above the values of present practice. Thermal breakdown is the most frequent and the values indicated for this by known material constants are also well above those of practice. The author states that there is no reason why, with a closer control of materials, field strengths of from 500 to 1,000 kilovolts per centimeter should not be possible on the basis of thermal instability alone.

Recent studies of conduction, absorption, and dielectric loss are as follows: A. Walther and Lydia Inge[34] have studied the conductivity of rock salt and glass at field strengths up to 2,000 kilovolts per centimeter. The conductivity increases as much as tenfold at high field strengths. From the conductivity-temperature relations, it is concluded that the increase of conductivity with field strength is largely due to an increase in ionic conductivity. Breakdown at room temperatures is shown to be thermal as well as electric. R. W. Sillars[35] attempts a model of Maxwell's complex dielectric, and Wagner's extension thereof, in a model of wax containing water drops. The theory is not supported by the results. Conclusion is reached that a minute amount of impurity in the form of fine needles can produce a serious alternating loss, while the effect of the same volume in spherical form would be negligible. W. A. Yager[36] also contributes in this field an exhaustive analysis of the distribution of relaxation times in complex dielectrics. The work is a careful examination of Wagner's proposal, which the results confirm, together with a somewhat extended explanation as to how the results of experiment can be utilized for determining the statistical distribution of relaxation times. The work tacitly assumes the Maxwell theory as the basis of dielectric absorption. G. A. Albert[37] measured dielectric losses parallel to the laminations of impregnated materials, showing values from 2 to 10 times the losses with field normal to laminations, depending upon the condition of the material. Thiessen, Winkel, and Herrmann[38] and Frei and Groetzinger[39] have studied the volumetric electric charges to be found in the rosin wax mixtures known as electrets. Evidence is presented that these are space charges which may have opposite signs, depending on the value of the stress applied during cooling. Thus not all of the behavior of the electret is due to dipolar orientation and fixation. Data as regards some of the new materials referred to in the first paragraph of this section are presented by M. Hagedorn[40] showing that polystyrol and similar substances can be prepared as foils with thickness from 0.02 millimeters up. Electrical properties vary with the material and proposal is made that these substances may be used in capacitors and cables. Standard Telephones and Cables[41] report new studies of the control of moisture in cellulose papers and fibers by esterification. Results on impregnated paper indicate acetic-acid values up to 30 per cent as about the limit to which this process can be extended without serious lowering of necessary physical properties of the paper.

A valuable paper is reported by C. Schmelzer[42] on the absolute measurement of dielectric losses at very high frequencies (3×10^7) with the capacitor-thermometer. The loss is measured as the heat liberated in a small cylindrical capacitor (maximum length, 0.5 centimeter) in a glass cell. An accuracy within 5 per cent is claimed. W. J. Shutt and H. Rogan[43] made a critical experimental investigation of the oscillation or "force" method of determining the dielectric constant of slightly conducting liquids. With the improved method described, results are reported indicating an accuracy of ±0.2 per cent for solutions of electrolytes having conductivities less than 0.005 mhos. J. A. Weh[44] describes methods of measuring the thermal conductivity of sheet materials, with a maximum inaccuracy of ±10 per cent. W. D. Buckingham[45] describes an experimental method for determining the equivalent resistance and capacitance network for an absorptive capacitor, at different frequencies and voltages. The method consists of an a-c bridge with the absorptive capacitor in one arm and an air capacitor in the opposite arm. To this capacitor are added series or shunt resistances adjusted by experiment to give complete balance. Balance is determined by complete disappearance of current as indicated by amplifier and cathode ray oscillograph. Value of the method is claimed in the construction of phantom circuits and in the operation of long communication cables. H. A. Thomas[46] presents an extensive study of the causes of relatively small variations in the capacitance of capacitors with solids and with air as dielectric. Special methods for the accurate measurement of capacitance are given, and methods proposed for controlling variations due to temperature.

High-Voltage Cables

The causes of instability and deterioration continue to occupy chief attention. In recent years we appear to have passed through a series of fashions in our ideas of the principal causes of cable deterioration. We have noted as chief suspect in successive periods, high inherent power factor and loss, gaseous ionization due to temperature cycles, wax formation, and oxidation. At the moment we appear to be leaving the oxidation period and reverting to that of gaseous ionization, through new methods for studying free gas spaces in the cable.

Physical structure and dielectric loss of impregnated paper, as related to the amount of contained air and under changes of voltage, temperature, frequency, and pressure, are reported in an analytical and speculative study by P. Junius.[47] The conclusions are that the shape of the power factor-voltage curves at different temperatures changes very little in a dielectric containing large amounts of air. On the other hand, the shape of these curves varies noticeably in well-impregnated cable. In the latter case the change of power factor due to temperature change may be much steeper than that for a cable containing air. An overpressure of one atmosphere is sufficient to cause a flat loss curve in a cable which contains much air. Thus comparison between the loss curves of a pressure cable and an ordinary cable not under pressure, should not be used as a basis of the relative excellence of the 2 cables. Since gas in a dielectric may be either above, at, or below atmospheric pressure, power-factor variation with pressure and temperature are better criteria than the variation with voltage. J. Lawton[48] presents a good review and analytical study of all American research on wax formation, and also a clear classification of oils as regards correlation between chemical structure and gas evolution. The properties of the 2 broad divisions of petroleum oil, the aliphatics and the carbocyclics, are well described, and the differences between polymerization and condensation, and the relation of these to molecular structure under ionic bombardment pointed out. Two papers from French sources have appeared on the leakage of oil from oil-filled cables in service, one by P. Capdeville,[49] and the other by M. R. Laroche.[50] These methods depend on differences in pressure caused by the leaks. They are very sensitive to temperature and pressure changes. Measuring apparatus and connections are described, a few test results are given, and a maximum inaccuracy of 3 per cent is claimed. P. Dunsheath[51] describes manufacturing equipment for the continuous extrusion of lead cable sheaths.

Of most recent interest is the work of K. S. Wyatt[52] and associates on the mechanical uniformity of cable insulaton. A new method is described for the examination of the cross section of the cable. Oil is extracted from a short length, which is then impregnated with styrene and then heated so as to solidify the latter. It is stated that in this condition an undistorted wafer, as thin as 5 mils can be cut from the cable. As the styrene is highly translucent, the wafer so prepared, when viewed against a light, affords a remarkably clear picture of the laminated structure of the cable, accentuating sharply all regions of separation or voids between layers, conductors, and sheath. In somewhat similar manner longitudinal sections may also be prepared. Complete publication of the results of these interesting studies are not yet available, but we are fortunate in having a paper on the subject from Mr. Wyatt at the annual meeting of this committee this year.

References

1. The Spark Gap as a Voltmeter, Professor W. M. Thornton. *World Power*, volume 26, September 1936, pages 69–71.

2. Koronaverluste bei Drehstrom, Von Karl Potthoff. *Elektrotechnische Zeitschrift*, volume 57, September 10, 1936, pages 1054–5.

3. Über Zeitkonstanten von Kondensatoren, Ernst Horst. *Archiv für Elektrotechnik*, volume 31, April 22, 1937, pages 273–81.

4. Über den Entladeverzug im gleichförmigen Feld bei grossen Schlagweiten, Robert Strigel. *Wissenschaftliche Veroffentlichüngen aus den Siemens-Werken*, volume 15, November 1936, pages 1–13.

5. Eine Prüfung der Tragergesetze für den Quecksilberdampf-Gleichrichterbogan, A. von Engel and M. Steenbeck. *Wissenschaftliche Veroffentlichugen aus den Siemens-Werken*, volume 15, November 1936, pages 42–59.

6. Die Stossdurchschlagspannung und der Stossdurchschlag im homogenen Felde bei niederen Drücken (100 bis 760 mm), Anton Kohler. *Archiv für Elektrotechnik*, volume 30, August 14, 1936, pages 528–52.

7. Der elektrische Durchschlag verschiedener Gase unter hohem Druck, E. Finkelmann. *Archiv für Elektrotechnik*, volume 31, April 22, 1937, pages 282–6.

8. Die Durchschlagsenkung bei Hochfrequenz, H. Bocker. *Archiv für Elektrotechnik*, volume 31, March 22, 1937, pages 166–178.

9. The Problem of the Mechanism of Static Spark Discharge, L. B. Loeb. *Reviews of Modern Physics*, volume 8, July 1936, page 267.

10. Very Short Time Lag of Sparking, Robert R. Wilson. *Physical Review*, volume 50, December 1, 1936, pages 1082–8.

11. The Townsend Coefficients and Spark Discharge, Daniel Q. Posin. *Physical Review*, volume 50, October 1, 1936, pages 650–8.

12. The Mechanism of the High Velocity of Propagation of Lightning Discharges, A. M. Cravath and L. B. Loeb. *Physics*, volume 6, April 1936, pages 125–7.

13. Durchschlagfestigkeit von flussigen und festen Benzol, W. Bahre. *Archiv für Elektrotechnik*, volume 31, March 22, 1937, pages 141–65.

14. Dielektrische Festigkeiten und Verluste flussiger Kohlenwasserstoffe mit und ohne Dipolcharakter, Richard Bredner. *Archiv für Elektrotechnik*, volume 31, June 15, 1937, pages 351–70.

15. Untersuchungen über die Beeinflüssung der Durchschlagspannung durch künstliche Olströmung und über die Erhöhung der Durchbruchfeldstärke durch elektrisches Filtern, E. Conradi. *Archiv für Elektrotechnik*, volume 31, March 22, 1937, 179–86.

16. Untersuchung über den Durchschlag und die Vorgänge bei elektrischer Beanspruchung in Isolierolen verschiedener Festigkeit, E. Conradi. *Archiv für Elektrotechnik*, volume 30, October 15, 1936, pages 677–82.

17. The Dielectric Strength of Noninflammable Synthetic Insulating Oils, F. M. Clark. Electrical Engineering, volume 56, June 1937, pages 671–6.

18. The Rapid Measurement of the Oxidation of Insulating Oils in Air. A. Gemant. *Transactions* of the Faraday Society, volume 32, November 1936, pages 1628–33.

19. Effect of Oxidation and Moisture on the Electrical Characteristics of Transactions Oil, J. F. Gillies and J. R. Black. *World Power*, volume 26, December 1936, pages 163–7.

20. Oil Oxidation in Impregnated Paper, J. B. Whitehead and T. B. Jones, presented at annual meeting, committee on electrical insulation, National Research Council, 1937.

21. Properties of Saturants for Paper-Insulated Cables, G. M. L. Sommerman. Electrical Engineering, volume 56, May 1937, pages 566–75.

22. Oxidation in Insulating Oil, J. B. Whitehead and F. E. Mauritz, Electrical Engineering, volume 56, April 1937, pages 465–74.

23. The Influence of Thin Metal Layers on the Deterioration of Technical Insulating Oils, P. J. Haringhuizen and D. A. Was. *Proc. Akad. Wet.*, volume 38, pages 567–1115.

24. Properties of Insulating Oil Recovered by High-Vacuum Distillation, T. Itoh and Y. Hyraki. *Journal* of the Institution of Electrical Engineers of Japan, volume 1, page 26.

25. An Electrical Investigation of the Polymerizing Oxidation Processes in Liquid Dielectrics, A. Lazarev and I. Raschektaev. *Technical Physics of the U.S.S.R.*, volume 3, 1936, pages 366–88.

26. Generation and Absorption of Gas in Insulating Oils Under the Influence of an Electric Discharge, G. W. Nederbragt. *Journal* of the Institution of Electrical Engineers, volume 79, September 1936, pages 282–90.

27. Thermionic Emission Into Dielectric Liquids, Edward B. Baker and Howard A. Boltz. *The Physical Review*, volume 51, February 15, 1937, pages 375–82.

28. Studies of the Electric Conductivity in Liquids of Low Dielectric Constant, K. H. Reiss. *Annalen der Physik*, volume 28, 1937, page 325.

29. Ionisation Des Dielectriques Liquides. Application Aux Rayons Cosmiques, M. G. Bialobrzeski. *Le Journal de Physique et la Radium*, volume 7, August 1936, pages 329–36.

30. Electric Breakdown Field Intensity of Water and Aqueous Solutions (letter to the editor), Y. Tariyama and U. Shinohara. *The Physical Review*, volume 51, April 15, 1937, page 680.

31. A Record of Recent Progress Towards the Correlation of the Chemical Composition, the Physical Constitution, and the Electrical Properties, of Solid Dielectric Materials, Willis Jackson. *Journal* of the Institution of Electrical Engineers, volume 79, November 1936, pages 565–76.

32. Impulse Voltage Strength of Insulators and Materials, J. C. Dowell and C. M. Foust. *General Electric Review*, volume 40, March 1937, pages 141–52.

33. Some Aspects of the Electric Strength of Dielectrics, S. Whitehead. *World Power*, volume 26, September 1936, pages 72–8.

34. Elektrische Leitfähigkeit Fester Dielektrika In Starken Elektrischen Feldern, Alexander Walther and Lydia Inge. *Technical Physics of the U.S.S.R.*, volume 3, 1936, pages 700–14.

35. The Properties of a Dielectric Containing Semiconducting Particles of Various Shapes, R. W. Sillars. *Journal* of the Institution of Electrical Engineers, volume 84, April 1937, pages 378–94.

36. The Distribution of Relaxation Times in Typical Dielectrics, Wm. A. Yager. *Physics*, volume 7, December 1936, pages 434–50.

37. Dielectric Loss Measurements Parallel to Laminations, Gerard A. Albert. *Journal of Applied Physics*, volume 8, March 1937, pages 218–26.

38. Elektrische Nachwirkungen im erstarrten Dieltekrikum, P. A. Thiessen, A. Winkel, and K. Herrmann. *Physikalische Zeitschrift*, volume 37, July 1936, pages 511–20.

39. Über das Freiwerden elektrischer Energie beim Aufschmelzen des Elektreten, H. Frei and G. Groetzinger. *Physikalische Zeitschrift*, volume 37, October 15, 1936, pages 720–24.

40. Gegossene Elektroisolierfolien, M. Hagedorn. *Kunststoffe*, volume 27, March 1937, pages 89–90.

41. Acetylated Paper, Standard Telephones & Cables, Ltd. *Electrician*, November 26, 1936, page 657.

42. Absolutmessung Dielectrischer Verluste bei hohen Frequenzen mit dem Kondensatorthermometer, Ch. Schmelzer. *Annalen der Physik*, volume 28, 1937, pages 35–53.

43. A Critical Experimental Investigation of the "Force" Method of Determining the Dielectric Capacity of Conducting Liquids at Low Frequencies, Univalent Electrolytes in Aqueous Solution, W. J. Schutt and H. Rogan. *Proceedings* of the Royal Society, volume 157, November 2, 1936, pages 359–72.

44. A Method of Measuring Thermal Conductivity of Insulating Materials, J. A. Weh. *General Electric Review*, volume 40, March 1937, pages 138–40.

45. Measurement of Condenser Characteristics at Low Frequencies, W. D. Buckingham. Presented at 1937 convention of the Institute of Radio Engineers.

46. The Electrical Stability of Condensers, H. A. Thomas. *Journal* of the Institution of Electrical Engineers, volume 79, September 1936, pages 297–335.

47. Physikalische Struktur und dielektrische Verluste fester Isolierstoffe, Doctor P. Junius. *Elektrotechnische Zeitschrift*, volume 57, May 7, 1936, pages 519–22.

48. Wax in Impregnated Paper Cables, J. Lawton. *World Power*, volume 26: part I—October 1936, page 98; part II—November 1936, pages 129–30.

49. La Recherche des Fuites D'Huile Dans Les Cables A Huile Fluide En Service, M. Pierre Capdeville. *Bulletin* de la Société Française des Electriciens, volume 7, April 1937, pages 459–70.

50. Sur La Localisation Des Fuites D'Huile Dans Les Cables A Huile Fluide Sous Pression, M. R. Laroche. *Bulletin* de la Société Française des Électriciens, volume 7, April 1937, pages 471–81.

51. Continuous Extrusion of Lead Cable-Sheaths, P. Dunsheath. *Journal* of the Institution of Electrical Engineers, volume 80, April 1937, pages 353–77.

52. Mechanical Uniformity of Cable Insulation and Methods for Its Measurement, K. S. Wyatt. Presented at annual meeting, committee on electrical insulation, National Research Council, 1937.

53. Bestrahlung und Durchschlag, W. Bogowski and Wallraf. *Zeitschrift fuer Physik*, volume 102, 1936, page 83.

54. Die Rolle Des Gases Beim Dürchschlag Von Flüssigen Isolatoren, Alexander Walther and Olga Tscheljustkino. *Technical Physics of the U.S.S.R.*, volume 3, 1936, pages 940–6.

Downstream face of the Tennessee Valley Authority's Wheeler Dam, the $37,000,000 project named after General Joseph Wheeler and dedicated formally September 10, 1937, on the 101st anniversary of the general's birth, although actually completed early in the year. The dam is some 15 miles upstream from the "war baby" Wilson Dam at Muscle Shoals (which has been deeded to the TVA by the government) and is intended to extend Tennessee River navigation some 74 miles upstream to the Guntersville Dam which is now under construction. This view shows the power house in the immediate foreground with the 2 45,000-horsepower outdoor-type generating units just beyond. Above at the right is the frame of the movable gantry crane, while across the river the outlines of the navigation lock and the high arched bridge over it may be seen. The dam is 72 feet high and 6,502 feet long, with a reservoir area of 67,100 acres

Sources of Engineering Income, 1929–34

Dealing with the annual incomes of engineers engaged in both engineering and nontechnical work, this sixth article[1] of a series reporting a survey of engineering employment conducted by the United States Bureau of Labor Statistics presents data, derived from reports of 52,589 engineers, tending to show that engineers engaged in technical work reach their maximum earning capacity later than those in nonengineering endeavors.

IN 1929 there was greater spread in the earnings of engineers engaged in nonengineering work than in those obtained from engineering work. Thus, among engineers 40 to 47 years of age, 10 per cent of those engaged in nonengineering earned more than $12,424 and 10 per cent earned less than $2,420 per year. The respective annual incomes of similar proportions of all those engaged in engineering work were $9,615 and $2,705; and of graduates in engineering $10,088 and $2,936.

The age of maximum earning power for engineers arrives more quickly for nonengineering than for engineering work. At 48 to 55 years of age, however, those college graduates who stayed in engineering were doing as well as those who had gone into nonengineering work. This was true even at the highest income levels.

Despite the fact that in 1929 the tendency was for average annual incomes of engineers engaged in nonengineering to exceed slightly those from engineering work, the opportunities in the former field did not embrace more than 7 per cent of the total in any one age classification.

Over the period 1929–34 the relationship changed between the jobs engineers took in engineering and nonengineering work. On the whole it appears that in 1929 nonengineering work was an alternative to engineering work, but from 1929 to 1934 many nonengineering jobs were accepted as an alternative to unemployment or work relief.

The extent to which earning opportunities from nonengineering work depreciated between 1929 and 1934 differs at the various age levels. The average earnings of 2 groups in nonengineering who were 28 to 40 years in 1929 declined by almost one-third from 1929 to 1934. As between the groups that were over 48 years in 1929 the average income of the 1934 group is only one-half the average of the 1929 group. Similarly at each of the other income levels a greater fall is found in the average income of older men in nonengineering.

Those who were able to stay in engineering fared better. Furthermore the changes which occurred in the earnings from engineering work, as reported by all engineers and by graduates only, were consistently uniform.

The relative changes as between nonengineering earnings and those for engineering work of engineers, with advancing age and experience, are also found to be the same for men with comparable periods of experience.

It was among those newcomers who were trying to force their way into the profession that the greatest fall in income occurred. Thus average earnings in engineering in 1934, 2 years after graduation, were 37 per cent less than in 1929. The earnings of those who had been out of college 10 years were 31 per cent lower in 1934 than in 1929. At higher ages all groups averaged a decrease of 26 per cent.

In 1934 almost one-tenth of the engineers were unemployed or on work relief at the end of the year. The low level of earnings of this group during 1934 contributed to lowering the average earnings of all engineers. Thus of those engineers who were unemployed at the end of 1934 the average earnings for the preceding 12 months of those who were less than 28 years of age ranged from $700 to $950. Engineers of 40 to 50 years averaged $1,350. Only about 10 per cent of the unemployed, even though they were in those ages at which engineering earnings reached a peak, had made as much as $2,000 in the preceding 12 months. Ten per cent made less than $300 a year.

Scope and Method

The earned annual-income data used in the preceding analysis were those reported for personal services of all classes of engineers, irrespective of whether or not they were engaged primarily in engineering or nonengineering work. They related, in other words, to the incomes of engineers, not to the incomes of men engaged in engineering. Consideration is here given to the annual incomes, classified by age, as related to the professional engineers' employment status.

While income was reported for the year, the type of employment was reported only as of December 31, 1929, 1932, and 1934. Consequently it has been necessary to assume that the kind of engineering or nonengineering employment engaged in at the end of the year was the source of the income for that year. This assumption makes possible valid general comparisons of the earnings of engineers in these 2 types of employment. But in that section dealing with the annual incomes of engineers who were unemployed, or who were employed on relief projects at the end of the year, it must not be assumed that they reflect the source of income. They are merely the incomes which had accrued during the year to those who were unemployed at the end of the year.

Before presenting the annual incomes from all kinds of engineering work and nonengineering work attention is directed to the following: It must be noted that the requirements of editing the questionnaires caused the selection of a relatively large proportion of the engineers engaged in nonengineering work in 1929 who had college degrees in engineering. Thus, elsewhere it has been shown that the general movement from 1929 to 1934 was out of engineering work either into unemployment or into work not in the engineering field. Consequently, a substantial number of those who were in pursuits other than engineering in 1929 would also have so reported in 1932 and 1934. Such returns from nonengineering graduates and "other" engineers were, in general, discarded. Therefore, the tabulations for nonengineering work in 1929 tend to be those of graduate engineers. On the other hand, a number of nongraduates who were practicing their profession in 1929 passed into nonengineering employment in 1932 and 1934. The schedules for such engineers were retained. Clearly the situation which prevailed in 1929 was less true in 1932 and 1934. Hence it is as well to compare the earnings for nonengineering both with the earnings of graduates and with those of all persons reporting who were engaged in engineering. These data are presented in table I.

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[1] An article prepared by Andrew Fraser, Jr., of the Division of Hours, Wages, and Working Conditions, Bureau of Labor Statistics, United States Department of Labor, which article was published in the September 1937 issue of *Monthly Labor Review*. Articles reporting other phases of this survey were published in ELECTRICAL ENGINEERING as follows: "Professional Aspects of Engineering Education," August 1936, pages 863–7; "Unemployment in the Engineering Profession," February 1937, pages 216–23; "Employment in the Engineering Profession," May 1937, pages 524–31; "Security of Engineering Employment," June 1937, pages 655–61; "Engineering Income and Earnings," September 1937, pages 1080–1104. A detailed report of the survey will be published later in bulletin form by the Bureau of Labor Statistics.

Caution should be exercised in comparing earnings with various types of employment in 1929, 1932, and 1934. The earnings of all engineers in engineering work reflect best the changes in what was being paid for engineering services. Both sets of figures of engineering earnings do reflect changes in the rates for given kinds and qualities of work. This is not true of the earnings from nonengineering; they indicate merely what individual engineers were able to earn in miscellaneous employments called "nonengineering." Conceivably such persons might all have been managers of industrial establishments in 1929 and gasoline-station attendants in 1932. Obviously a decrease in earnings from nonengineering employment would not

Table I. Comparison of 5 Levels of Annual Earnings From Nonengineering and Engineering Work Reported in 1929, 1932, and 1934

Age	Year of Graduation	Years After Graduation	Proportion With Annual Earnings of More Than Specified Amount as Derived From—														
			10 Per Cent			25 Per Cent			50 Per Cent			75 Per Cent			90 Per Cent		
			Nonengineering Work by All Engineers[1]	Engineering Work by—		Nonengineering Work by All Engineers[1]	Engineering Work by—		Nonengineering Work by All Engineers[1]	Engineering Work by—		Nonengineering Work by All Engineers[1]	Engineering Work by—		Nonengineering Work by All Engineers[1]	Engineering Work by—	
				All Engineers[1]	All Graduates		All Engineers[1]	All Graduates		All Engineers[1]	All Graduates		All Engineers[1]	All Graduates		All Engineers[1]	All Graduates
1929 Income (in Dollars)																	
64 years and over	Prior to 1889	41+	(³)	9,937	10,148	(³)	6,917	7,346	2,400	4,476	4,971	(³)	3,060	3,469	(³)	1,957	2,413
56–63 years	1889–96	33–40	(³)	12,625	13,516	7,155	7,500	7,955	4,400	4,979	5,590	2,893	3,422	3,760	(³)	2,420	2,624
48–55 years	1897–1904	25–32	12,495	11,709	12,478	7,867	7,108	7,610	5,057	4,912	5,232	3,494	3,481	3,777	2,280	2,661	3,020
40–47 years	1905–12	17–24	12,424	9,815	10,088	8,106	6,407	6,747	5,346	4,562	4,876	3,408	3,405	3,624	2,420	2,705	2,936
36–39 years	1913–16	13–16	10,140	7,751	8,294	6,620	5,680	6,099	4,347	4,102	4,353	3,013	3,210	3,354	1,998	2,582	2,756
32–35 years	1917–20	9–12	8,052	6,480	6,578	5,502	4,814	4,988	3,685	3,672	3,822	2,792	3,010	3,146	1,945	2,458	2,581
28–31 years	1921–24	5–8	5,460	4,753	4,842	4,099	3,776	3,847	3,042	3,145	3,207	2,349	2,577	2,664	1,642	2,150	2,258
26–27 years	1925–26	3–4	4,170	3,618	3,641	3,075	3,104	3,124	2,331	2,558	2,582	1,821	2,164	2,200	1,308	1,850	1,891
24–25 years	1927–28	1–2	2,910	3,043	2,992	2,344	2,501	2,477	1,786	2,105	2,095	1,407	1,834	1,831	889	1,476	1,493
23 years	1929	0	2,496	2,356	2,165	1,973	1,938		1,500	1,322	1,168	936	888	862	446	502	449
1932 Income (in Dollars)																	
67 years and over	Prior to 1889	44+	(³)	9,009	9,386	(³)	6,032	6,363	3,000	3,846	4,100	(³)	2,242	2,469	(³)	1,145	1,233
59–66 years	1889–96	36–43	(³)	9,020	9,643	5,000	6,252	6,589	2,550	4,126	4,689	1,200	2,640	3,143	(³)	1,300	1,571
51–58 years	1897–1904	28–35	9,146	8,405	9,008	5,069	5,892	6,163	3,011	4,046	4,411	1,395	2,823	3,119	525	1,807	1,989
43–50 years	1905–12	20–27	9,188	7,567	7,979	5,528	5,242	5,557	3,129	3,742	4,007	1,528	2,720	2,968	736	1,903	1,999
39–42 years	1913–16	16–19	7,450	6,387	6,700	4,980	4,643	4,990	2,800	3,490	3,711	1,602	2,604	2,854	809	1,926	2,090
35–38 years	1917–20	12–15	5,486	5,579	5,858	3,675	4,191	4,400	2,320	3,223	3,381	1,276	2,475	2,664	587	1,851	1,999
31–34 years	1921–24	8–11	4,290	4,332	4,415	3,007	3,457	3,546	1,963	2,790	2,885	1,123	2,195	2,299	490	1,619	1,728
29–30 years	1925–26	6–7	3,301	3,501	3,565	2,465	2,934	2,799	1,639	2,411	2,455	964	1,942	1,990	454	1,468	1,533
27–28 years	1927–28	4–5	2,463	3,005	3,021	1,908	2,504	2,521	1,319	2,103	2,128	765	1,702	1,751	306	1,257	1,310
26 years	1929	3	2,034	2,518	2,504	1,585	2,140	2,134	1,045	1,871	1,878	570	1,523	1,546	228	1,119	1,169
25 years	1930	2	1,930	2,167	2,155	1,465	1,946	1,941	1,069	1,662	1,658	585	1,325	1,324	234	937	927
24 years	1931	1	1,766	2,039	2,014	1,348	1,742	1,725	921	1,394	1,381	470	1,024	1,008	188	539	515
23 years	1932	0	1,689	1,910	1,826	1,240	1,335	1,243	814	766	716	406	383	358	163	153	143
1934 Income (in Dollars)																	
69 years and over	Prior to 1889	46+	(³)	7,367	7,570	(³)	5,155	5,513	2,500	3,292	3,700	(³)	1,861	2,225	(³)	1,050	1,229
61–68 years	1889–96	38–45	(³)	8,460	9,372	(³)	5,700	6,264	2,200	3,793	4,280	(³)	2,294	2,625	(³)	1,105	1,160
53–60 years	1897–1904	30–37	7,848	7,951	8,548	4,147	5,443	5,841	2,523	3,745	4,095	1,305	2,520	2,751	631	1,558	1,711
45–52 years	1905–12	22–29	9,171	7,230	7,665	5,426	4,980	5,271	3,040	3,524	3,788	1,579	2,526	2,688	921	1,826	1,893
41–44 years	1913–16	18–21	7,293	6,221	6,542	4,576	4,518	4,863	2,892	3,319	3,540	1,667	2,471	2,655	1,042	1,829	1,966
37–40 years	1917–20	14–17	5,560	5,393	5,656	3,667	4,058	4,278	2,414	3,101	3,271	1,514	2,379	2,525	848	1,839	1,960
33–36 years	1921–24	10–13	4,101	4,323	4,405	3,055	3,387	3,499	1,992	2,676	2,801	1,276	2,113	2,219	694	1,625	1,752
31–32 years	1925–26	8–9	3,560	3,554	3,601	2,468	2,892	2,949	1,700	2,380	2,442	1,123	1,929	2,002	526	1,513	1,581
29–30 years	1927–28	6–7	2,658	3,066	3,120	2,028	2,507	2,533	1,439	2,106	2,141	1,015	1,745	1,806	500	1,298	1,362
28 years	1929	5	2,209	2,635	2,658	1,764	2,209	2,227	1,296	1,929	1,946	934	1,593	1,621	431	1,244	1,266
27 years	1930	4	2,149	2,370	2,371	1,621	2,044	2,044	1,224	1,789	1,797	889	1,431	1,443	408	1,083	1,093
26 years	1931	3	2,028	2,155	2,146	1,536	1,900	1,895	1,171	1,578	1,571	835	1,265	1,261	352	954	949
25 years	1932	2	1,793	2,002	1,999	1,442	1,701	1,693	1,118	1,396	1,392	815	1,107	1,104	336	837	835
24 years	1933	1	1,664	1,911	1,895	1,325	1,562	1,551	991	1,272	1,265	606	960	954	242	526	520
23 years	1934	0	1,388	1,391	1,311	1,093	976	939	744	642	617	372	321	309	149	128	123

[1] That is, includes all graduates and all "other" engineers.

[2] Between 50 and 100 engineers reported.

[3] Between 10 and 50 engineers reported.

Table II. Comparison of 5 Levels of Annual Earnings From Engineering Work, for 5 Age Groups of Older Graduates[1] Reporting in 1929, 1932, and 1934

Per Cent of Specified Income Level	Engineers With Annual Earnings of More Than Specified Amount, Whose Ages Were—											
	60 in 1929	63 in 1932	65 in 1934	38 in 1929	41 in 1932	43 in 1934	30 in 1929	33 in 1932	35 in 1934	25 in 1929	28 in 1932	30 in 1934
10 per cent	13,516	9,643	9,372	8,294	6,700	6,542	4,842	4,415	4,405	2,992	3,021	3,120
25 per cent	7,955	6,589	6,264	6,099	4,990	4,863	3,847	3,546	3,499	2,477	2,521	2,533
50 per cent	5,590	4,689	4,280	4,353	3,711	3,540	3,207	2,885	2,801	2,095	2,128	2,141
75 per cent	3,760	3,143	2,625	3,354	2,854	2,655	2,664	2,299	2,219	1,831	1,751	1,860
90 per cent	2,624	1,571	1,160	2,756	2,090	1,966	2,258	1,728	1,752	1,443	1,310	1,362
	Percentage Increase or Decrease											
	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34
10 per cent	−31	−29	− 3	−21	−19	−2	− 9	− 9	(2)	+4	+ 1	+3
25 per cent	−21	−17	− 5	−20	−18	−3	− 9	− 8	−1	+2	+ 2	(2)
50 per cent	−23	−16	− 9	−19	−15	−5	−13	−10	−3	+2	+ 2	+1
75 per cent	−30	−16	−16	−21	−15	−7	−17	−14	−3	−1	− 4	+3
90 per cent	−56	−40	−26	−29	−24	−6	−23	−24	+1	−9	+12	+4

[1] Includes postgraduates, nonengineering graduates, and first-degree engineering graduates who were professionally active prior to 1930.

[2] Less than one per cent.

then measure the fall in earnings of industrial managers. Actually the changes reflect the composite effect of a lowering of pay for various types of nonengineering work and a lowering of the quality of nonengineering work that was accepted as an alternative to unemployment.

Finally, among those reported at the end of the year as engaged in both engineering and nonengineering, there were some who suffered unemployment during part of the year. Inasmuch as unemployment was far more common in 1932 and 1934 than in 1929, this accounts for part of the decreases in annual incomes previously noted for both engineering and nonengineering. As regards engineering, rate change alone will be more fully analyzed later when monthly earnings from engineering employment are presented.[2]

Incomes From Engineering and Nonengineering Work

The first significant point of comparison between the incomes in 1929 of engineers engaged in engineering and those in nonengineering work is that the earnings of the latter showed greater dispersion. Thus, among engineers 40 to 47 years of age, 10 per cent of those engaged in nonengineering earned more than $12,424 and 10 per cent earned less than $2,420 per year. The respective annual incomes for similar proportions of all those in engineering work were $9,815 and $2,705; and of graduates in engineering $10,088 and $2,936. It seems apparent from these figures and others for 1929, that on the one hand many engineers were attracted out of engineering jobs by favorable opportunities, whereas, on the other hand, an almost equally large proportion dropped out of engineering work and were forced to find alternative employment. This point appears to be substantiated by a consideration of the variation in the relationship between engineering and nonengineering earnings in moving from the lowest to the highest of the 5 income levels.

Only at the lowest 10-per-cent income group or level did engineering incomes exceed those from nonengineering work at all ages for which comparison can be made. At the middle levels the engineering incomes were greater than nonengineering by only 10 per cent at 25 and 27 years of age, and by only 5 per cent at age 30. From this point the more rapid advance in average nonengineering earnings to a maximum at age 44 brought about an equalization of the incomes near to age 34 at a value of $3,700 per year. They again equalized at 54 years. That is, between 44 and 54 years, while the average returns from nonengineering had declined from $5,346 to $4,900, those from engineering had advanced from $4,562 to $4,900. The advance in the latter continued to age 60, attaining a value of $4,979 per year, as against $4,400 for nonengineering at the same age. At the upper 10- and 25-per-cent income groups or levels engineering work ceased to have an advantage over nonengineering near age 26. Thereafter the latter diverged upward from the former to reach a maximum of $12,495 at age 52 at the highest level, and of $8,106 at age 44 in the case of the next lowest level. The corresponding values of engineering earnings were $11,709 and $6,407 per annum. The steady advance in engineering earnings, together with the declines in nonengineering earnings, brought about an equalization of incomes at age 58.

A second point of significance is that in 1929 engineering work as such ultimately offered rewards as high as engineers were able to find in nonengineering. This arose primarily from the fact that the age of maximum earning power for engineers arrived more quickly for nonengineering than for engineering work. For at 48 to 55 years of age those college graduates who stayed in engineering were doing proportionately as well as those who had gone into nonengineering. This was true even at the highest income levels. The earnings of the upper 10 per cent of

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2. In the present article it must be borne in mind that the influence of unemployment in decreasing annual income was probably somewhat more important among those who reported nonengineering work as the source of income. It has been stated that the major direction of flow was from engineering work into nonengineering work. While some such transfers were made without an intervening period of unemployment, there must have been unemployment for many who lost an engineering job and went into nonengineering work after failure to find work of an engineering nature.

Table III. Comparison of 5 Levels of Annual Earnings, for Corresponding Years After Graduation, in 1929, 1932, and 1934

Age of Engineers	Years After Graduation	Proportion With Annual Earnings of More Than Specified Amount														
		10 Per Cent			25 Per Cent			50 Per Cent			75 Per Cent			90 Per Cent		
		1929	1932	1934	1929	1932	1934	1929	1932	1934	1929	1932	1934	1929	1932	1934
Nonengineering work—all engineers:																
23½ years	½	$2,496	$1,889	$1,388	$1,973	$1,240	$1,093	$1,500	$814	$744	$936	$406	$372	$446	$163	$149
25 years	2	2,910	1,850	1,710	2,344	1,380	1,365	1,786	990	1,040	1,407	520	685	880	210	275
28 years	5	4,560	2,463	2,160	3,320	1,908	1,680	2,525	1,319	1,250	1,995	765	910	1,410	306	420
33 years	10	7,320	4,290	3,770	5,060	3,007	2,640	3,500	1,963	1,790	2,670	1,123	1,170	1,840	490	575
43 years	20	11,950	7,950	7,293	7,780	5,140	4,576	5,100	2,880	2,892	3,390	1,580	1,667	2,340	785	1,042
53 years	30	(1)	9,130	8,400	7,730	5,200	4,770	4,970	3,050	2,775	3,420	1,425	1,435	(1)	570	760
60 years	37	(1)	(1)	(1)	7,155	5,020	(2)	4,400	2,725	2,400	2,893	1,270	(2)	(1)	(1)	(1)
Engineering work—all engineers:																
23½ years	½	2,356	1,910	1,391	1,933	1,335	976	1,322	766	642	888	383	321	502	153	128
25 years	2	3,043	2,100	1,960	2,501	1,840	1,610	2,105	1,520	1,310	1,834	1,150	1,020	1,476	690	650
28 years	5	3,910	3,005	2,470	3,320	2,504	2,115	2,750	2,103	1,840	2,280	1,702	1,490	1,940	1,257	1,150
33 years	10	5,940	4,332	3,800	4,480	3,457	3,020	3,520	2,790	2,470	2,890	2,195	2,000	2,385	1,619	1,550
43 years	20	9,400	6,660	6,221	6,250	4,800	4,518	4,440	3,580	3,319	3,400	2,660	2,471	2,690	1,920	1,829
53 years	30	11,900	8,230	7,620	7,060	5,640	5,180	4,900	3,990	3,620	3,460	2,790	2,530	2,650	1,840	1,680
60 years	37	12,625	8,800	8,150	7,500	6,130	5,550	4,979	4,070	3,750	3,422	2,710	2,440	2,420	1,470	1,370
Engineering work—graduates only:																
23½ years	½	2,165	1,826	1,311	1,858	1,243	939	1,168	716	617	862	358	300	440	143	128
25 years	2	2,992	2,100	1,940	2,477	1,840	1,610	2,095	1,510	1,310	1,831	1,150	1,015	1,493	690	650
28 years	5	4,030	3,021	2,470	3,360	2,521	2,110	2,800	2,128	1,840	2,375	1,751	1,505	2,010	1,310	1,170
33 years	10	6,100	4,415	3,860	4,660	3,546	3,110	3,680	2,885	2,530	3,040	2,299	2,110	2,495	1,728	1,640
43 years	20	10,350	7,100	6,542	6,620	5,140	4,863	4,770	3,865	3,540	3,600	2,890	2,655	2,910	2,060	1,966
53 years	30	12,500	8,820	8,100	7,620	5,980	5,560	5,270	4,320	3,910	3,780	3,030	2,710	2,960	1,980	1,790
60 years	37	13,516	9,400	8,850	7,955	6,400	5,980	5,590	4,580	4,150	3,760	3,080	2,690	2,624	1,710	1,460
		Per Cent of Increase or Decrease														
		1929–34	1929–32	1932–34	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34	1929–34	1929–32	1932–34
Nonengineering work—all engineers:																
23½ years	½	−44	−32	−18	−45	−37	−12	−50	−46	− 9						
25 years	2	−41	−36	− 8	−42	−41	− 1	−42	−45	+ 5	−51	−63	+32	−69	−76	+31
28 years	5	−53	−46	−12	−48	−43	−12	−50	−48	− 5	−54	−62	+19	−70	−78	+37
33 years	10	−48	−41	−12	−50	−41	−16	−49	−44	− 9	−56	−58	+ 4	−69	−73	+17
43 years	20	−39	−33	− 8	−41	−34	−11	−43	−44	(3)	−51	−53	+ 6	−55	−66	+33
53 years	30			− 8	−38	−33	− 8	−44	−39	− 9	−58	−58	+ 1			+33
60 years	37					−30		−45	−38	−12		−56				
Engineering work—all engineers:																
23½ years	½	−41	−19	−27	−50	−31	−27	−51	−42	−16						
25 years	2	−36	−31	− 7	−36	−26	−13	−38	−28	−14	−44	−37	−11	−56	−53	− 6
28 years	5	−37	−23	−18	−36	−25	−16	−33	−24	−13	−35	−25	−12	−41	−35	− 9
33 years	10	−36	−27	−12	−33	−23	−13	−30	−21	−11	−31	−24	− 9	−35	−32	− 4
43 years	20	−34	−29	− 7	−28	−23	− 6	−25	−19	− 7	−27	−22	− 7	−32	−29	−5
53 years	30	−36	−31	− 7	−27	−20	− 8	−26	−19	− 9	−27	−19	− 9	−37	−31	− 9
60 years	37	−35	−30	− 7	−26	−18	− 9	−25	−18	− 8	−29	−21	−10	−43	−39	− 7
Engineering work—graduates only:																
23½ years	½	−30	−16	−28	−49	−33	−24	−47	−30	−14						
25 years	2	−35	−30	− 8	−35	−26	−13	−37	−28	−13	−45	−37	−12	−56	−54	− 6
28 years	5	−39	−25	−18	−37	−25	−16	−34	−24	−14	−37	−26	−14	−42	−35	−11
33 years	10	−37	−28	−13	−33	−24	−12	−31	−22	−12	−31	−24	− 8	−34	−31	− 5
43 years	20	−37	−31	− 8	−27	−22	− 5	−26	−19	− 8	−26	−20	− 8	−32	−29	− 5
53 years	30	−35	−29	− 8	−27	−22	− 7	−26	−18	− 9	−28	−20	−11	−40	−33	−10
60 years	37	−35	−30	− 6	−25	−20	− 7	−26	−18	− 9	−28	−18	−13	−44	−35	−15

[1] Between 50 and 100 engineers reported.

[2] Between 10 and 50 engineers reported.

[3] Less than one per cent.

the college graduates continued to advance from $10,088 at age 44 to $13,516 at 60. The average at these ages rose from $4,876 to $5,590, whereas the average from nonengineering fell from $5,346 to $4,400 between these ages.

From the preceding analysis, therefore, it appears that in 1929 the tendency was for average annual incomes of engineers who engaged in nonengineering work to exceed slightly those from engineering work. Notwithstanding, it should be noted that the opportunities outside the engineering field did not embrace more than 7 per cent of the total reporting in any one age classification. Furthermore, since there is no knowledge of the basis of selection, it cannot be said that nonengineering earnings would have been greater or less for the engineer had he stayed in engineering work. The only justifiable assumption is that in 1929 there was a preference to remain in engineering by those in the 2 lower income groups or levels and a definite tendency to accept attractive openings in nonengineering work at the 2 higher income levels. The turning point in this movement occurred near to the middle levels of income reported.

Changes in Income, 1929 to 1934

In an earlier article the changes from 1929 to 1934 in the incomes of all engineers were analyzed on an age basis. The decreases noted were due partly to salary reductions

Table IV. Comparison of 5 Levels of Earned Annual Income in 1932 and 1934, for All Engineers Reporting Unemployment, on an Age Basis

Without Regard to Type of Education

Age	Year of Graduation	Years After Graduation	Proportion Earning More Than Specified Amount: 10 Per Cent	25 Per Cent	50 Per Cent	75 Per Cent	90 Per Cent
			1932 Income				
67 years and over	Prior to 1889	44 and over	(1)	(1)	(1)	(1)	(1)
59–66 years	1889–96	36–43	(2)	(2)	$720	(2)	(2)
51–58 years	1897–1904	28–35	$2,453	$1,477	793	$396	$159
43–50 years	1905–12	20–27	2,790	1,867	1,105	528	211
39–42 years	1913–16	16–19	2,497	1,574	1,008	494	198
35–38 years	1917–20	12–15	2,420	1,417	1,057	559	223
31–34 years	1921–24	8–11	2,150	1,416	932	462	185
29–30 years	1925–26	6–7	1,754	1,250	761	380	152
27–28 years	1927–28	4–5	1,690	1,178	751	375	150
26 years	1929	3	1,232	925	605	303	121
25 years	1930	2	1,280	907	581	290	116
24 years	1931	1	1,233	891	588	294	118
20–23 years	1932	0	(3)	754	503	251	(3)
			1934 Income				
69 years and over	Prior to 1889	46 and over	(2)	(2)	$1,000	(2)	(2)
61–68 years	1889–96	38–45	(2)	$1,300	688	$344	(2)
53–60 years	1897–1904	30–37	$2,349	1,700	1,080	542	$217
45–52 years	1905–12	22–29	2,546	1,943	1,357	748	299
41–44 years	1913–16	18–21	2,151	1,730	1,357	867	353
37–40 years	1917–20	14–17	2,250	1,780	1,316	769	308
33–36 years	1921–24	10–13	1,959	1,634	1,304	836	340
31–32 years	1925–26	8–9	2,138	1,746	1,243	716	287
29–30 years	1927–28	6–7	1,796	1,495	1,045	546	219
28 years	1929	5	1,805	1,417	893	449	180
27 years	1930	4	1,638	1,374	948	534	214
26 years	1931	3	1,545	1,210	836	419	167
25 years	1932	2	1,548	1,200	716	358	143
24 years	1933	1	1,460	1,107	756	378	151
20–23 years	1934	0	1,257	881	571	285	114

[1] Less than 10 persons reported. [2] Between 10 and 50 persons reported. [3] Between 50 and 100 persons reported.

on given jobs. They were also due to the fact that incomes were reduced by extended periods of unemployment and by the necessity for accepting poorer jobs. That article described what happened between 1929 and 1934 on the average, for example, to engineers 40 to 47 years of age.

From the data presented in table I it is now possible to trace more precisely the influence of these several factors on the incomes of engineers. The first point to be noted is that the relationship changed between the jobs that engineers took in engineering and nonengineering work. In 1929 the essential elements of the story are to be found in the similarities of earnings in the 2 fields, rather than in the differences. On the whole it appears that nonengineering work was an alternative to engineering work. But from 1929 to 1934 many nonengineering jobs were accepted as an alternative to unemployment or work relief. Thus, the average earnings of those who were 40 to 47 years of age in 1929 and were in nonengineering work were $5,346. In 1934 a larger number of men from this age class were in nonengineering, and the average of this larger group was $3,040, a decline of 43 per cent. By way of contrast the average annual income of graduates in engineering work of from 40 to 47 years of age was $4,876 in 1929. A smaller number still in engineering in 1934 averaged $3,788, a decrease of only 23 per cent.

The extent to which earning opportunities from nonengineering work depreciated between 1929 and 1934 differed at the various age levels. The average earnings of 2 groups in nonengineering whose ages were 28 to 40 in 1929 declined by almost one-third from 1929 to 1934. As between the groups of those who were over 48 in 1929, the average income of the 1934 group was only half the average of the 1929 group. Similarly at each of the other income levels there was a greater fall in the average income of older men in nonengineering.

Those who were able to stay in engineering fared better. As illustrating this point, table II is presented, covering graduates of advancing age and experience, who were engaged in engineering work. A similar table based on the data in table I might be presented for all engineers. Essentially, however, the changes which occurred in the earnings from engineering work, as reported by all engineers and by graduates only, were consistently uniform.

In the period from 1929 to 1934 the average earnings of graduates in engineering who were 60 years old in 1929 declined 23 per cent. There was a smaller decrease for the middle-aged groups, and among those averaging 30 years of age in 1929 the decline amounted to 13 per cent. For the youngest groups shown in the table—those who were 25 in 1929 and 30 in 1934—the 5 years of added experience resulted in an actual increase in the average earnings of those who remained in engineering in 1934, as against the average for the larger numbers in the profession in 1929. The nature and extent of these changes in the averages of graduate earnings from engineering work were closely paralleled by those which occurred at the 2 upper income groups or levels. The increase in average earnings that was noted at 25 and 30 years did not occur for this age group at the 2 lower levels of income for the period 1929

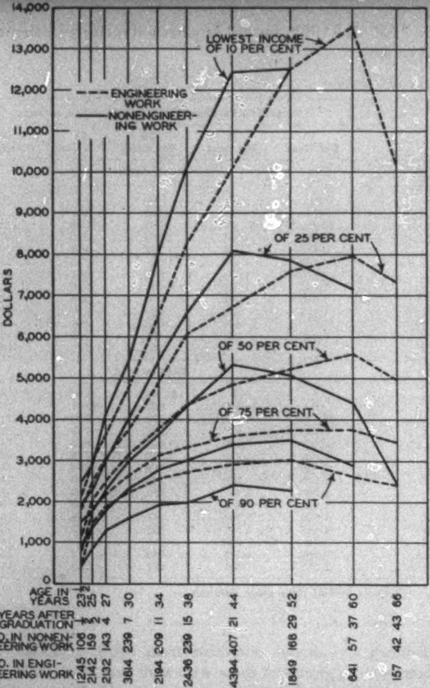

Figure 1. Earned annual income of professional engineers in engineering and nonengineering work by age in 1929

Primarily income reported by graduate engineers in either full- or part-time employment

to 1934. Furthermore, the declines in earnings for the lowest 10 per cent in each of the 3 older groups were greater than the average.

The relative changes as between nonengineering earnings and those for engineering work of engineers with advancing age and experience are also found to be the same for men with comparable periods of experience (table III).

As far as the comparison of nonengineering and engineering earnings is concerned, this table merely reenforces the evidence already advanced as to the severe fall of income that occurred when engineers were forced out of the profession. However, the table sets forth more clearly than table II the picture of the fall of earnings from engineering. It was among those newcomers who were trying to force their way into the profession that the greatest fall of income occurred. Thus, average earnings in engineering in 1934, 2 years after graduation, were 37 per cent less than in 1929. The earnings of those who had been out of college 10 years were 31 per cent lower in 1934 than in 1929. At higher ages all groups averaged a decrease of 26 per cent. A similar movement occurred in the level of earnings of the upper and lower 25 per cent of those in engineering, but at the level of the upper 10 per cent the declines were greater for the older engineers.

Income of Unemployed Engineers

In 1934 almost one-tenth of the reporting engineers were unemployed or on work relief at the end of the year. The low level of earnings of this group during 1934 contributed to lowering the average earnings of all engineers.

The distribution of the earnings of this group has significance only as indicating the income which a group, unemployed in December 1934, had earned in the preceding 12 months. Some were probably men who had had a few months' work at a good rate, and a long period of unemployment. Others may have worked quite steadily at a low rate and become recently unemployed. All were unemployed at the end of the year. They could look back on average earnings for the preceding 12 months of $700 to $950 if they were less than age 28, while those of 40 to 50 had averaged $1,350. Only about 10 per cent of the unemployed, even though they were in those ages at which engineering earnings reach a peak, had made as much as $2,000 in the preceding 12 months. Ten per cent had made less than $300 a year.

Correction. In the previous article of this series, September issue, page 1092, sentence beginning in line 11, right-hand column should read: "Some 479 reported incomes less than $800 per year, while 295 earned more than $19,000 per year.

Steel Structures Identified Magnetically

A PAPER "Steel Structures Identified and Flaws Located by Means of Balancing Wave Tests" was presented by Carl Kinsley (A'97, F'35, member for life), consulting engineer, New York, N. Y., at the annual meeting of the American Society for Testing Materials held in New York, N. Y., June 28–July 2, 1937. The fundamental assumption of the method is that magnetic hysteresis loops uniquely characterize any ferromagnetic material with respect to its structure and physical condition. The magnetic "finger print" is standardized and recorded by using a simple sine wave of magnetizing force which produces a cyclical magnetic flux in the material which, in turn, causes a complex induced electromotive force in a secondary testing circuit. This is quantitatively analyzed by the testing apparatus into its equivalent Fourier series of harmonic terms which are then recorded as the complete characterization of the material.

It has not been found possible to make any change in the material without having a corresponding change in one or more of the constants of its characteristic series of terms. No different combination of analysis, metallurgical structure, or physical condition has been found that would produce a duplicate of the characteristic equation of the specimen.

The correctness of the fundamental assumption was questioned in the discussion at the meeting, and the author indicated that it had been verified in every case examined throughout the whole range of laboratory investigations.

The Cause and Elimination of Noise in Small Motors

By W. R. APPLEMAN
MEMBER AIEE

Common Causes of Noise

MUCH OF the noise present in electrical motors is due to poor manufacture. Careless or inaccurate manufacturing methods often show up in some manner as uneven air gaps, loose bearings, brush noise, or loose rotor bars.

It is beyond the scope of this article to discuss either the various production problems or special noise insulating mountings. We shall rather confine ourselves to a discussion of the electrical design features as the selection of the proper slot combinations, winding distribution, and skew.

Slot Combinations

The number of stator slots is usually fairly well set, or at least the selection is limited because of the number of poles and phases. We shall confine ourselves, therefore, to the proper selection of the number of rotor bars after the number of stator slots is decided upon.

An interesting example of the method used by one electrical manufacturer with an excellent reputation shows what work can be saved. About 17 different type rotors all using different numbers of bars were made up. The 3 or 4 quietest were selected and the head of the department chose the quietest one as the standard. A couple of years later one rotor was calculated which would decrease the harmonics. This rotor was quieter than the rotor selected after 17 attempts. I realized then that elimination of noise was not just the lucky finding of a good *combination* after many trials, but calculations were worthwhile. Had 3 or 4 quiet rotors been calculated and the best one selected much money and time would have been saved and better results secured. This same company received a number of complaints concerning a noisy 4-pole motor with a 17-bar rotor. As soon as the motors were used a short time by critical customers they were returned because of noisy bearings. Actually the bearing fits were still close and the noise was caused by a magnetic force.

If 2 fields exist which differ by 2 poles a rotor vibration will be set up. The unbalanced pull will be proportional to the product of the magnitude of the 2 fields. This noise will increase with the load because the magnitude of both fields increases with the load. This vibration will sound very much like a loose bearing condition. If 2 fields exist which differ by 4 poles a rotating elliptical field will be set up. A heavy or rigid yoke section will prevent this. Polarity differences of more than 4 poles will seldom cause any trouble. In fact 2 fields differing by 4 poles seldom give rise to very much noise. Our next step then is to list the harmonics present, determine whether there are some with fields with a 2-pole difference and if so, eliminate them. The harmonics caused by the slot openings have $2(P/2 \text{ plus } m)$ and $2(P/2 \text{ minus } m)$ poles. These must be figured for the following values of m:

m = number stator slots. (These particular harmonics will show up in the winding calculations and cannot be eliminated or even altered by the winding distribution)
m = number rotor slots
m = difference between number of stator and rotor slots
P = number of poles

In the example cited with a 24-slot stator and 17- and 26-bar rotors for 4 poles we have:

24 slots (stator)	$2\,(2 + 24) = 52$ poles
	$2\,(2 - 24) = -44$ poles
17 slots (rotor)	$2\,(2 + 17) = 38$ poles
	$2\,(2 - 17) = -30$ poles
7 slots (difference)	$22\,(2 + 7) = 18$ poles
	$2\,(2 - 7) = -10$ poles
26 slots (rotor)	$2\,(2 + 26) = 56$ poles
	$2\,(2 - 26) = -48$ poles
2 slots (difference)	$2\,(2 + 2) = 8$ poles
	$2\,(2 - 2) = 0$ poles

Next the field harmonics set up by the stator winding were calculated from the formula $N = \pm (2\phi g \pm 1)$, in which

N = order of the harmonic
ϕ = number of phases
g = any positive integer

It will be noted from the formula that all odd harmonics can be present on single phase and all odd except thirds and multiples of thirds on 3 phase. The number of poles present in the harmonic field is equal to the order of the harmonic multiplied by the number of poles of the fundamental.

The number of poles of the stator field harmonics present are therefore as shown in table I.

The strength of these fields and the direction of rotation

Table I

N (Harmonics)	Number Poles
1	4
3	12
5	20
7	28
9	36
11	44
13	52
15	60

A paper recommended for publication by the AIEE committee on electrical machinery. Manuscript submitted April 14, 1937; released for publication September 20, 1937.

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Table II

	2-Pole Motor	4-Pole Motor	6-Pole Motor	8-Pole Motor
24 slots	50	52	54	56
	−46	−44	−42	−40
33 slots	68	70	72	74
	−64	−62	−60	−58
9 slots	20	22	24	26
	−16	−14	−12	−10
34 slots	70	72	74	76
	−66	−64	−62	−60
10 slots	22	24	26	28
	−18	−16	−14	−12

Table III

N	Number Poles	Number Poles	Number Poles	Number Poles
1	2	4	6	8
3	6	12	18	24
5	10	20	30	40
7	14	28	42	56
9	18	36	54	72
11	22	44	66	88
13	26	52	78	104
15	30	60	90	120
17	34	68	102	136
19	38	76	114	152
31	62			
33	66			
35	70			
37	74			

can be calculated as shown in another chapter of this paper.

Note then that the 17-slot rotor has 30 poles and the field 28 (seventh harmonic), also that the 17-slot rotor has 38 poles and the field 36 (ninth harmonic). Note again that the 7-slot difference has 10 poles and the field 12 (third harmonic), also 18 poles and the field 20 (fifth harmonic).

If, however, we use a 26-slot rotor which we did try, and adopt as standard there is a 4-pole difference and at no point a 2-pole difference. The increased quietness due to the use of a larger number of rotor bars, elimination of the 2-pole harmonic difference, and proper skew showed a marked decrease in noise, not only under load but also with no load.

Another motor with 33 rotor bars worked satisfactorily on 6 poles, but was not very quiet on 4 poles. Let us analyze the motor from the standpoint of harmonic fields with a 2-pole difference for the various numbers of fundamental poles. Also check a 34-bar rotor with the 24-slot stator. The results are shown in table II.

The number of poles of the stator field harmonics present are therefore as shown in table III.

From these tables we gather this information:

1. To avoid a difference of 2 poles between the harmonic fields it is necessary to use a rotor with an even number of rotor slots for 2- and 4-pole motors.
2. The 33-slot rotor is very good for a 6-pole motor having a difference of 6 poles between all the harmonic fields.
3. The 34-bar rotor is satisfactory for 6 poles having a minimum difference of 4 poles.
4. The 33-slot is not good for 8 poles as a 2-pole difference exists.
5. The 34-slot is satisfactory for 8 poles as it has a minimum difference of 4 poles.

Probably the most commonly used stator punching is one in approximately a 6-inch diameter with 36 slots. A very satisfactory rotor for this stator is one with 44 slots. This can be readily checked by the method just illustrated. A further check will eliminate such rotors as 39- or 41-bar for general purpose work.

It is very evident from the preceding work that it would be of great help to have 2 sets of tables for rapid checking of rotors. One of these tables consists of the number of poles present caused by stator field harmonics. Since all odd harmonics are present this will be the order of each odd harmonic multiplied by the number of poles of the fundamental. The other table is for the harmonics caused by slot openings and the difference existing due to slot openings.

More recent investigation and articles have added still more to our fund of knowledge on the selection of the number of rotor bars which will let us design our motor still quieter and eliminate some that we would still retain if we tried all those without a 2-pole difference.

Kron states: "Vibration and noise are liable to be present as follows:

1. When the slots differ by one or by the number of poles plus or minus one, transverse vibration and noise may occur.

Table IV. Pitch Fractions

Decimal Fraction	Slot Value	See Table
1.00	18/18 15/15 etc.	V
0.9445	17/18	XIV
0.9333	14/15	XIII
0.9166	11/12	XII
0.9	9/10	XI
0.889	8/9	X
0.875	7/8	IX
0.8667	13/15	XIII
0.833	5/6	VIII
0.8	8/10	XI
0.778	7/9	X
0.75	3/4	VII
0.7333	11/15	XIII
0.7222	13/18	XIV
0.7	7/10	XI
0.667	2/3	VI
0.625	5/8	IX
0.6112	11/18	XIII
0.6	6/10	XI
0.5833	7/12	XII
0.556	5/9	X
0.533	8/15	XIII
0.5	1/2	V
0.4667	7/15	XIII
0.444	4/9	X
0.4166	5/12	XII
0.4	4/10	XI
0.3889	7/18	XIV
0.375	3/8	IX
0.333	1/3	VI
0.3	3/10	XI
0.2778	5/18	XIV
0.2667	4/15	XIII
0.25	1/4	VII
0.222	2/9	X
0.2	2/10	XI
0.1667	1/6	VIII
0.1333	2/15	XIII
0.125	1/8	IX
0.111	1/9	X
0.1	1/10	XI
0.0833	1/12	XII
0.0667	1/15	XIII
0.0556	1/18	XIV

2. When the slots differ by half the number of poles, torsional vibration and noise may occur.

3. When the slots differ by the number of poles, torsional vibration and noise may occur and also rumbling noise unaccompanied by critical vibrations.

"The chance that the noise occurs in the working range is greater with smaller number of poles, higher speed, and with small transverse or torsional critical speeds. When these noises do occur the motor is practically useless."

The reader has probably already noticed by rule 2 torsional vibration and noise may occur in our example of the 24-slot stator and 26-bar rotor. Probably partly due to the relatively heavy yoke section this did not occur. Had we, however, avoided 26 and 28 slots because of rules 2 and 3 and avoided 30- and 32-slot because of fear of locking in points on starting we would probably have tried a 34-bar rotor. Actual experience with another firm has showed us that a 24-slot stator and a 34-bar rotor makes a quiet 4-pole motor. All combinations falling under rule 1 have a 2-pole difference, and should therefore be avoided for a double reason.

Table V

2 Slots Per Pole

Pitch	Full (1.00)	1/2 (0.5)
m = 1	127.32	90.03
3	42.45	−30.01
5	25.47	−18.01
7	18.19	12.86
9	14.15	10.00
11	11.58	− 8.184
13	9.795	− 6.925
15	8.488	6.002
17	7.49	5.296
19	6.702	− 4.739
21	6.064	− 4.287
23	5.536	3.914
25	5.094	3.601
27	4.716	− 3.335
29	4.39	− 3.104
31	4.108	2.905
33	3.859	2.728

Table VI

3 Slots Per Pole

2/3	1/3
0.667	0.3333
110.27	63.66
0.00	−42.45
− 22.06	12.73
− 15.75	9.095
0.00	−14.15
10.02	5.787
8.48	4.897
0.00	− 8.488
− 6.487	3.745
− 5.805	3.351
0.00	− 6.064
4.795	2.768
4.411	2.547
0.00	− 4.716
− 3.803	2.195
− 3.558	2.054
0.00	− 3.859

Table VII

4 Slots Per Pole

Pitch	3/4	1/4
m = 1	117.63	48.72
3	16.24	−39.22
5	− 9.744	23.53
7	− 16.81	− 6.96
9	− 13.07	− 5.414
11	− 4.429	10.694
13	3.748	− 9.05
15	7.843	3.248
17	6.92	2.866
19	2.564	− 6.192
21	− 2.32	5.602
23	− 5.115	− 2.118
25	− 4.706	− 1.949
27	− 1.804	4.357
29	1.68	− 4.056
31	3.795	1.572
33	3.565	1.476

Table VIII

6 Slots Per Pole

5/6	1/6
0.833	0.1667
122.96	32.95
30.01	−30.01
6.59	24.6
− 4.707	−17.57
− 10.00	10.00
− 11.18	− 2.995
− 9.46	− 2.535
− 6.002	6.002
− 1.938	− 7.234
1.734	6.472
4.287	− 4.287
5.346	1.433
4.919	1.318
3.335	− 3.335
1.136	4.24
− 1.063	− 3.967
− 2.728	2.728

It is advisable for the designer to also bear rules 2 and 3 in mind as the discussion so far would not eliminate some undesirable combinations. For a 2-pole design rule 2 would again eliminate rotors which would cause a 2-pole difference.

A general statement, subject to all the limitations of a general statement follows:

Any rotor with a number of rotor slots divisible by the number of pairs of poles of the fundamental and which differs from the number of stator slots by more than the number of poles will probably be a quiet rotor.

This does not apply to 2-pole motors as the above rule will give a motor with a difference between the number of harmonic poles equal to the number of poles of the fundamental. This rule does not cover all possibilities as it does not include rotors that would have a 4-pole difference on a 6- or 8-pole motor or a 6-pole difference on an 8-pole motor, etc. It might also be mentioned before leaving the subject that small slot openings will give rise to less violent flux disturbance than large slot openings. Rotors with closed slots should be machined accurately to keep the same thickness of steel outside the various bars. Care must also be taken in the selection of the number of rotor slots to prevent locking in at starting.

Winding Distribution for Sinusoidal Wave Form

In our section on the selection of the number of rotor bars we showed how to calculate which harmonics could be present in the field. There are 2 ways to reduce the strength of the harmonics and consequently reduce the noise. One is to design the stator punching with heavy teeth at the center of the pole and lighter teeth toward the outside of the pole, and the other is to distribute the winding to decrease the harmonic. The former method is patented and each punching is applicable to but one given number of poles. It is well for each manufacturing company to have on hand a set of tables showing the harmonic strength for the various fractions of the pole pitch based on 100 turns. A discussion of how these may be calculated will be explained later. I am including with this thesis blue prints of the table I use. Often, the designer has little interest in knowing the strength of the various harmonics provided he has his winding distributed in the best way. The author has worked out 2 simple methods for calculating this which as far as he knows are original.

Table IX

	8 Slots Per Pole			
Pitch	7/8	5/8	3/8	1/8
	0.875	0.625	0.375	0.125
m = 1	124.86	105.86	70.73	24.84
3	35.23	−8.28	−41.63	−23.58
5	14.15	−24.98	4.969	21.14
7	3.549	−10.1	15.12	−17.84
9	−2.76	7.859	−11.74	13.87
11	−6.43	11.35	−2.258	−9.608
13	−8.13	1.911	9.605	5.44
15	−8.325	−7.046	4.715	−1.656
17	−7.345	−6.218	−4.161	−1.461
19	−5.563	1.307	6.572	3.723
21	−3.368	5.946	−1.183	−5.032
23	−1.08	3.075	−4.595	5.429
25	0.9936	−2.829	4.228	−4.995
27	2.62	−4.625	0.92	3.915
29	3.644	−0.8565	−4.305	−2.438
31	4.028	3.41	2.282	0.8014
33	3.784	3.203	2.143	0.753

Table X

	9 Slots Per Pole					
Pitch	8/9	7/9	5/9	4/9	2/9	1/9
	0.889	0.778	0.556	0.444	0.222	0.111
m = 1	125.38	119.64	97.53	81.84	43.55	22.11
3	36.76	21.22	−21.22	−36.76	−36.76	−21.22
5	16.37	−4.422	−23.93	−8.71	25.08	19.51
7	6.222	−13.93	3.159	17.92	−11.69	−17.09
9	0.00	−14.15	14.15	0.00	0.00	14.15
11	−3.959	−8.866	2.01	−11.4	7.44	−10.88
13	−6.295	−1.701	−9.204	3.35	−9.65	7.502
15	−7.35	4.244	−4.244	7.35	7.35	−4.244
17	−7.377	7.038	5.738	−4.815	−2.562	1.301
19	−6.6	6.297	5.133	−4.308	−2.292	1.164
21	−5.25	3.031	−3.031	5.25	5.25	−3.031
23	−3.558	−0.9612	−5.202	1.893	−5.45	4.24
25	−1.742	−3.90	0.884	−5.02	3.274	−4.785
27	0.00	−4.716	4.716	0.00	0.00	4.716
29	1.501	−3.362	0.762	4.325	−2.822	−4.125
31	2.64	−0.715	−3.86	−1.405	4.046	3.146
33	3.34	1.929	−1.929	−3.34	−3.34	−1.929

METHOD *A*

Let us assume a 36-slot stator to be wound 4 poles or 9 slots per pole. We want to make all the harmonics small or in other words approach a sine wave.

If the stator pole were wound with a single coil the wave form would be a rectangle. If more than one coil per pole were used the wave form would be a series of rectangles above each other, giving a resultant wave with a number of steps. Figures 1 and 2 illustrate this. As the number of slots per pole and the number of coils per pole are increased the shape of the wave will approach that of a sine wave. Since in actual practice neither is infinity nor any where near it, it is necessary that we allot the proper number of turns to each coil to make the wave as nearly a sine wave as possible. The following method of calculation is not empirical but theoretically sound. Figure 4 is the layout for a winding over 2, 4, 6, and 8 teeth for 9 slots per pole and figure 3 is its flux wave. The point of zero flux is at the center of the teeth between adjacent poles. There will be 180/9 equals 20 electrical degrees between adjacent teeth. The ordinates of the sine wave at the various teeth are as follows:

sine 20 degrees = 0.342 at teeth *B*
sine 40 degrees = 0.643 at teeth *D*
sine 60 degrees = 0.866 at teeth *F*
sine 80 degrees = 0.985 at teeth *H*

Since the wave will actually have a flat top and the maximum flux will be in teeth *B* let us call this point 100 per cent. The percentage of flux in the various teeth which is also the percentage of the total turns in all coils which surround these teeth is as follows:

tooth *B:* 0.342/0.985 = 0.347
tooth *D:* 0.643/0.985 = 0.653
tooth *F:* 0.866/0.985 = 0.879
tooth *H:* 0.985/0.985 = 1.000

Since all the flux in teeth *B* is caused by the coils in slots *A* then 0.347 of the total turns per pole lie in slots *A*. The flux in teeth *D* is caused by the coils in both slots *A* and *C*. The turns in slots *C* must therefore be 0.653 minus 0.347

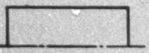

Figure 1

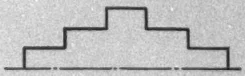

Figure 2

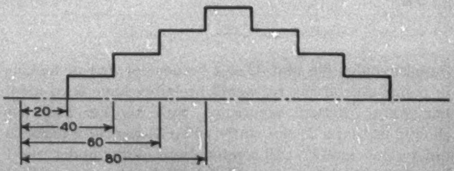

Figure 3. Flux wave

Table XI

	10 Slots Per Pole							
Pitch	9/10 0.9	8/10 0.8	7/10 0.7	6/10 0.6	4/10 0.4	3/10 0.3	2/10 0.2	1/10 0.1
m = 1	125.76	121.1	113.45	103.00	74.84	57.8	39.346	19.916
3	37.82	24.95	6.64	− 13.11	−40.37	−41.92	−34.34	−19.27
5	18.01	0.00	− 18.01	− 25.47	0.00	18.01	25.47	18.01
7	8.258	− 10.69	− 17.97	− 5.62	17.3	2.845	−14.71	−16.21
9	2.213	− 13.46	− 6.422	11.445	− 8.316	−12.61	4.372	13.974
11	− 1.8105	− 11.01	5.254	9.363	− 6.804	10.31	3.577	−11.43
13	− 4.446	− 5.757	9.674	− 3.027	9.316	− 1.532	− 7.922	8.728
15	− 6.002	0.00	6.002	− 8.488	0.00	− 6.002	8.488	− 6.002
17	− 6.674	4.403	− 1.171	− 2.314	− 7.124	7.399	− 6.06	3.4
19	− 6.62	6.374	− 5.972	5.422	3.939	− 3.042	2.071	− 1.048
21	− 5.99	5.767	− 5.402	4.905	3.564	− 2.752	1.874	− 0.948
23	− 4.933	3.254	− 0.866	− 1.711	− 5.266	5.468	− 4.479	2.513
25	− 3.601	0.00	3.601	− 5.093	0.00	− 3.601	5.093	− 3.601
27	− 2.141	− 2.772	4.658	− 1.452	4.486	− 0.7377	− 3.815	4.202
29	− 0.6868	− 4.176	1.993	3.552	− 2.58	3.912	1.357	− 4.337
31	0.6426	− 3.907	− 1.865	3.323	− 2.415	− 3.66	1.27	4.058
33	1.752	− 2.268	− 3.811	− 1.192	3.67	0.6036	− 3.121	− 3.438

equals 0.306 of the turns per pole. The turns in slots *E* will be 0.879 minus 0.653 equals 0.226 and in slots *G* will be 1.00 minus 0.879 equals 0.121. This method is fundamentally sound and I recommend it to anyone interested in an exact derivation. It too is quite simple involving only 3 steps namely:

1. Looking up the sine values of the angles.
2. Correcting to a percentage basis using the maximum sine value of the particular wave as 100 per cent.
3. Subtracting from each value the value listed directly above it.

There is another type of distribution which includes the use of a full-pitch coil. We know that in practice we cannot get 2 full coils in this slot so it will be interesting to see what we should have for nearly sinusoidal wave form. We shall again use 9 slots per pole with the winding distributed over 3, 5, 7, and 9 teeth as shown in figures *E* and *F*.

sine 10 degrees = 0.174 = 18.5 per cent.
sine 30 degrees = 0.500 = 53.2 per cent.
sine 50 degrees = 0.766 = 81.5 per cent.
sine 70 degrees = 0.940 = 100.0 per cent.
Percentage of turns over 3 teeth = 18.5 per cent
Percentage of turns over 5 teeth = 53.2 per cent
Percentage of turns over 5 teeth = 53.2 per cent
−18.5 per cent = 28.3 per cent
Percentage of turns over 7 teeth = 81.5 per cent
−53.2 per cent = 34.7 per cent
Percentage of turns over 9 teeth = 100.0 per cent
−81.5 per cent = 18.5 per cent

100.0 per cent

Method *B*

Another method of calculating the percentage of turns in each coil and which involves no subtraction is still simpler. The ratio of the number of teeth spanned by the particular coil to the total number of teeth per pole is first calculated. The sine of this fraction times 90 degrees is calculated for each coil and the sum of these sines considered to be 100 per cent. The various sines expressed as a percentage of the sum of the sines is the percentage of the total number of turns per pole in the individual coil. Assume again the 36-slot stator with the winding over 2, 4, 6, and 8 teeth.

sine 2/9 × 90 degrees = sine 20 degrees = 0.342/2 teeth.
sine 4/9 × 90 degrees = sine 40 degrees = 0.643/4 teeth.
sine 6/9 × 90 degrees = sine 60 degrees = 0.866/6 teeth.
sine 8/9 × 90 degrees = sine 80 degrees = 0.985/8 teeth.

Total turns per pole equals 100 per cent = 2.836

The percentage of the total turns per pole allotted to the particular coil is then in direct proportion to the ratio of the sine of that particular angle to the sum of the sines of the angles. This expressed in percentage of the total turns per pole is:

Over 2 teeth = 0.121 or 0.342/2.836
Over 4 teeth = 0.227 or 0.643/2.836
Over 6 teeth = 0.306 or 0.866/2.836
Over 8 teeth = 0.346 or 0.985/2.836

1.000 = 100 per cent

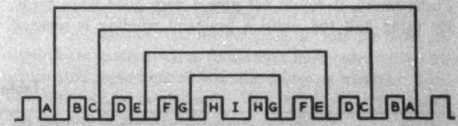

Figure 4. Winding distribution, 9 slots per pole wound over 2, 4, 6, and 8 teeth

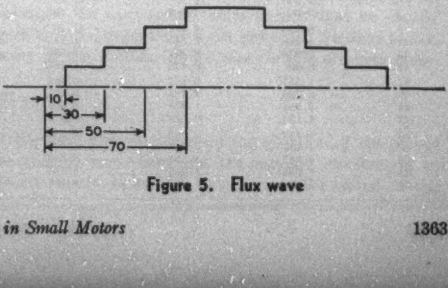

Figure 5. Flux wave

Table XII

12 Slots Per Pole				
	11/12	7/12	5/12	1/12
Pitch	0.9166	0.5833	0.4166	0.0833
m = 1	126.23	101.00	77.5	16.616
3	39.22	−16.24	−39.22	−16.24
5	20.20	−25.25	−3.323	15.50
7	11.07	−2.374	18.035	−14.43
9	5.414	13.07	−5.414	13.07
11	1.51	7.046	−9.18	−11.476
13	−1.278	−5.962	7.769	9.712
15	−3.248	−7.843	3.248	−7.843
17	−4.56	0.9775	−7.427	5.941
19	−5.316	6.644	0.874	−4.08
21	−5.602	2.32	5.602	2.32
23	−5.488	−4.391	−3.37	−0.7224
25	−5.049	−4.04	−3.10	−0.6645
27	−4.357	1.805	4.357	1.805
29	−3.483	4.352	0.573	−2.672
31	−2.50	0.536	−4.073	3.258
33	−1.476	−3.565	1.476	3.565

Table XIV

18 Slots Per Pole						
	17/18	13/18	11/18	7/18	5/18	1/18
Pitch	0.9445	0.7223	0.6111	0.3889	0.2778	0.0555
m = 1	126.82	115.39	104.29	73.02	53.81	11.096
3	40.99	10.98	−10.98	−40.99	−40.99	−10.984
5	23.08	−14.61	−25.37	2.22	20.86	10.76
7	14.90	−18.12	−7.69	16.49	−1.585	−10.43
9	10.00	−10.00	10.00	−10.00	−10.00	10.00
11	6.638	1.009	10.49	−4.892	11.53	−9.48
13	4.14	8.023	−0.854	9.756	−5.617	8.876
15	2.197	8.198	−8.198	−2.197	−2.197	8.198
17	0.653	3.166	−4.295	−6.136	6.788	7.46
19	−0.584	−2.83	3.843	5.49	−6.074	−6.675
21	−1.569	−5.856	5.856	1.569	1.569	5.856
23	−2.34	−4.534	0.482	−5.514	3.175	−5.017
25	−2.92	−0.444	−4.616	2.153	−5.073	4.172
27	−3.333	3.333	−3.333	3.333	3.333	−3.333
29	−3.596	4.373	1.855	−3.979	0.383	2.518
31	−3.723	2.356	4.092	−0.358	−3.365	−1.736
33	−3.727	−0.998	0.998	3.727	3.727	0.998

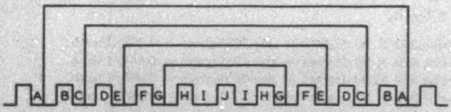

Figure 6. Winding distribution; 9 slots per pole wound over 3, 5, 7, and 9 teeth

Since in production it is desirable to wind the smaller coils with less turns the winding of motors for sinusoidal wave form is further desirable. It appears at present that this method can also be applied to windings where the poles overlap provided a half coil is used for the outer coil. The angle for this coil would always be 90 degrees and the sine of 90 degrees is one. A calculation with a full coil would be an impossible winding since there would be no slot room for the adjacent pole except in light starting windings. Furthermore, it would not give a very good wave form. By using half the value a practical winding is secured and one with more nearly a sinusoidal wave form. In a motor using 9 slots per pole we would then calculate the percentage of the total turns per pole for each slot as follows when using a winding over 3, 5, 7, and 9 teeth.

sine 3/9 × 90 degrees = sine 30 degrees = 0.500/3 teeth.
sine 5/9 × 90 degrees = sine 50 degrees = 0.766/5 teeth.
sine 7/9 × 90 degrees = sine 70 degrees = 0.940/7 teeth.
$^1/_2$ sine 9/9 × 90 degrees = $^1/_2$ sine 90 degree = 0.500

100 per cent = 2.706

Percentage of turns over 3 teeth = 0.50/2.706 = 18.5 per cent
Percentage of turns over 5 teeth = 0.766/2.706 = 28.3 per cent
Percentage of turns over 7 teeth = 0.940/2.706 = 34.7 per cent
Percentage of turns over 9 teeth = 0.50/2.706 = 18.5 per cent

100.0 per cent

The few minutes spent to determine how a winding should be distributed are well spent. Instead of depending on a lucky guess mathematics is used.

Table XIII

15 Slots Per Pole								
	14/15	13/15	11/15	8/15	7/15	4/15	2/15	1/15
Pitch	0.933	0.8667	0.733	0.5333	0.4667	0.2667	0.1333	0.0667
m = 1	126.61	124.53	116.31	94.62	85.2	51.79	26.47	13.31
3	40.37	34.34	15.12	−24.95	−34.34	−40.37	−24.95	−13.12
5	22.06	12.73	−12.73	−22.06	−12.73	22.06	22.06	12.73
7	13.52	1.902	−17.79	7.40	16.62	−3.78	−18.09	−12.17
9	8.316	−4.373	−11.45	13.46	4.373	−8.316	13.46	11.45
11	4.708	−7.746	−1.21	−2.406	−11.32	11.51	−8.602	−10.574
13	2.036	−8.947	6.554	−9.74	−1.024	−7.278	3.984	9.58
15	0.00	−8.488	8.488	0.00	8.488	0.00	0.00	−8.488
17	−1.557	−6.842	5.012	7.448	−0.783	5.566	−3.047	7.326
19	−2.726	−4.485	−0.701	1.393	−6.555	−6.664	4.98	−6.122
21	−3.564	−1.874	−4.905	−5.766	1.874	3.564	−5.766	4.905
23	−4.114	0.5787	−5.414	−2.252	5.057	1.151	5.505	−3.704
25	−4.411	2.546	−2.546	4.411	−2.546	−4.411	−4.411	2.546
27	−4.485	3.816	1.457	2.772	−3.816	4.485	2.722	−1.457
29	−4.365	4.294	4.010	−3.263	2.938	−1.786	−0.913	0.459
31	−4.085	4.018	3.753	−3.053	2.749	−1.671	−0.854	0.429
33	−3.670	3.122	1.193	2.268	−3.122	3.67	2.268	−1.193

Table XV. Strength of Harmonics for Various Distributions

9 Slots Per Pole

h	1-1-1-1 over 4-6-6-10	1-1-1-1 over 2-4-6-8	1-1-1-1 over 3-5-7-9	1-2-2-1 over 3-5-7-9	2-2-2-1 over 3-5-7-9	1-2-2-3 over 2-4-6-8	1-1-1 over 4-6-8
1	100	100	100	100	100	100	100
3	8.29	− 10.2	0	0	− 6.15	0.00	0.00
5	0.436	2.96	0.933	− 2.96	− 0.833	1.6	− 6.1
7	3.3	− 0.915	4.04	0.92	5.01	1.43	1.96
9	0.0	0	0	0.0	− 2.05	0	0
11	− 2.1	0.58	2.33	0.6	1.37	− 0.906	1.68
13	− 0.397	− 1.14	0.927	− 1.14	− 0.322	− 0.615	1.74
15	− 1.66	2.03	0	0.0	− 1.23	0.0	0
17	− 5.88	− 5.88	5.87	5.88	5.87	− 5.95	− 5.93
19	− 5.25	− 5.26	5.26	5.27	5.25	− 5.33	− 5.25
21	− 1.18	1.45	0	0.0	− 0.89	0.0	0
23	− 0.0968	− 0.642	0.526	− 0.633	− 0.182	− 0.346	0.985
25	− 0.924	0.255	0.113	0.257	0.603	− 0.4	− 0.74
27	0	0	0	0.0	− 0.685	0	0
29	1.02	− 0.221	0.972	0.0616	0.374	0.6	0.635
31	0.716	0.477	0.389	0.478	0.135	0.257	− 0.73
33	0.745	0.925	0	0.0	0.56	0.843	0

h	1-2-3 over 4-6-8	1-1-1 over 5-7-9	2-2-1 over 5-7-9	A*	B**	C†	D††
1	100	100	100	100	100	100	100
3	10.8	12.2	7.55	− 0.08	4.6	20.6	1.43
5	− 0.548	− 0.835	− 5.66	0.00	0.92	6.1	− 1.3
7	0.75	2.15	− 0.578	− 0.04	1.44	4.2	1.16
9	0.00	4.1	2.52	0.00	0.00	4.0	− 0.953
11	− 0.477	1.37	− 0.38	− 0.02	0.92	2.8	− 0.279
13	− 0.212	− 0.322	− 2.14	0.008	1.24	2.3	− 0.524
15	− 2.17	2.46	1.51	0.01	0.92	4.1	0.286
17	− 5.88	5.88	5.88	− 5.88	− 5.88	6.5	6.49
19	− 5.27	5.3	5.25	− 5.27	− 5.25	5.3	5.8
21	− 1.55	1.76	1.08	− 0.09	− 0.64	2.9	0.203
23	0.119	− 0.153	− 1.21	− 0.09	0.73	1.3	− 0.29
25	− 0.21	0.6	0.169	0.01	− 0.427	− 0.25	0.331
27	0.00	0.137	0.84	0.00	0.00	0.00	− 0.27
29	0.18	0.52	− 0.685	0.08	0.41	0.2	0.386
31	− 0.089	− 0.095	− 0.88	0.00	− 0.52	0.2	− 0.209
33	0.985	0.112	0.688	0.01	− 0.42	0.8	0.132

* *A* is 0.122 over 2, 0.226 over 4, 0.306 over 6, and 0.346 over 8 teeth

** *B* is 0.258 over 4, 0.348 over 6, and 0.394 over 8 teeth

† *C* is 0.167 over 5, 0.333 over 7, and 0.500 over 9 teeth. (This is the same as 1-2-3 over 5-7-9)

†† *D* is 0.185 over 3, 0.283 over 5, 0.347 over 7, and 0.185 over 9 teeth

Table XV showing the relative strengths of the different harmonics of the above winding distribution shows how small the harmonics are. This table also shows a number of other possible distributions, some with harmonics as high as 10 to 20 per cent of the fundamental. That this is an undesirable condition from both a torque and noise standpoint need hardly be mentioned, but it should bring forcibly to the designer's attention the desirability of distributing the winding for sinusoidal wave form.

My suggestion to the designer is to calculate the percentage of total turns in each slot for the various distributions he most frequently uses. He will then refer to this sheet when calculating each new winding. I am including the most common distributions in table XVI. For the man who wants to figure the strength of the harmonic fields, I suggest that he also make a set of tables for the strength of the various harmonics for the individual coils of the pole.

The strengths of the various harmonics for each individual coil of the pole are figured and are added algebraically to get the strength of the various harmonics for the complete pole. Careful attention must be paid to the signs.

I am including some of my tables with this article to help the designer. He will very probably note that there are 2 harmonics which regardless of the method of winding distribution he cannot overcome. The number of these harmonics is twice the number of stator slots per pole plus or minus one. If, for example, 9 slots per pole are used the seventeenth and nineteenth harmonics cannot be eliminated regardless of how the motor is wound. They can, however, be skewed out. This will be discussed under the subject of skew.

It should also be mentioned that it is at times necessary for the designer to secure special results as for example in the design of a 2-speed motor. He usually develops what is known among engineers as a freak circuit. When this is the case it is sometimes so complicated and impossible to calculate the various harmonics present that he usually goes back to the method of cut and try. Needless to say, some of the motors using these circuits are very noisy.

Skew

We have already discussed the selection of the proper number of rotor bars and the winding distribution to secure nearly sinusoidal wave form. We noted in the section on wave form that there were 2 harmonics always present regardless of how we wound the stator.

We know that if we want to get a current flow in a wound armature we must put one side of each coil under a north pole and the other side under a south pole. If we should place both sides of the coil under like poles no current would flow. One theory of skew is based exactly on this idea. Referring again to our case of 9 slots per pole we have the seventeenth and nineteenth harmonics present regardless of the method of winding. We shall assume that there are no other bad harmonics because proper winding distribution was used. Since the fundamental has 4 poles the seventeenth and nineteenth harmonics have 68 and 76 poles, respectively, or 34 and 38 pairs of poles. It is now our object to place one end of the rotor bar under one north harmonic pole and the other end under another north harmonic pole. This will prevent any current flowing in the rotor caused by the harmonic pole.

The rotor should be skewed 1/34 of the entire rotor to eliminate the seventeenth harmonic and 1/38 of the entire rotor to eliminate the nineteenth harmonic. If we were using a 44-bar rotor the skew to eliminate the seventeenth harmonic would be 1/34 times 44 equals 1.29 bar skew. To eliminate the nineteenth harmonic we would need 1/38 times 44 equals 1.16 bar skew. If the rotor were held as nearly commercially as possible to these limits there should be little trouble caused by the seventeenth and nineteenth harmonics. Now that we have pointed out the best skew from a harmonic viewpoint let us point out the

Table XVI. Winding Distribution for Sinusoidal Wave Form

Tooth Span	Per Cent Turns Per Slot					Tooth Span	Per Cent Turns Per Slot				
18 Slots Per Pole											
4	6.3					3	4.6				
6	9.0	9.6				5	7.5	7.8			
8	11.6	12.4	13.7			7	10.2	10.6	11.5		
10	13.8	14.7	16.4	18.9		9	12.5	13.2	14.2	16.1	
12	15.7	16.7	18.4	21.3	26.3	11	14.5	15.2	16.5	18.6	22.2
14	17.0	18.1	20.0	23.2	28.6	13	16.0	16.8	18.2	20.6	24.6
16	17.8	18.9	20.9	24.3	29.9	15	17.1	17.9	19.5	22.0	26.2
18	9.0	9.6	10.6	12.3	15.2	17	17.6	18.5	20.1	22.7	27.0
KW	0.808	0.835	0.873	0.909	0.944		0.794	0.820	0.854	0.892	0.927
16 Slots Per Pole											
4	7.9					3	5.8				
6	11.3	12.4				5	9.4	10.0			
8	14.4	15.7	17.9			7	12.7	13.4	14.9		
10	17.2	18.5	21.1	25.7		9	15.4	16.4	18.2	21.4	
12	18.9	20.5	23.4	28.5	38.4	11	17.6	18.7	20.8	24.5	31.1
14	20.0	21.8	24.9	30.8	40.8	13	19.2	20.4	22.6	26.5	33.8
16	10.3	11.1	12.7	15.5	20.8	15	19.9	21.1	23.5	27.6	35.1
KW	0.812	0.848	0.889	0.928	0.963		0.797	0.829	0.868	0.910	0.946
12 Slots Per Pole											
2	6.8					3	10.3				
4	13.2	14.1				5	16.5	18.3			
6	18.6	20.0	23.3			7	21.4	24.0	29.3		
8	22.8	24.5	28.5	37.2		9	25.0	27.8	34.1	48.2	
10	25.4	27.3	31.8	41.4	65.9	11	26.8	29.9	36.6	51.8	
12	13.2	14.1	16.4	21.4	34.1						
KW	0.789	0.829	0.883	0.936	0.977		0.809	0.854	0.910	0.959	
9 Slots Per Pole											
2	13.1					3	18.5				
4	22.7	25.7				5	28.3	34.7			
6	30.6	34.8	47.8			7	34.7	42.6	65.3		
8	34.6	39.5	52.2			9	18.5	22.7	34.7		
KW	0.793	0.855	0.920				0.821	0.893	0.961		
8 Slots Per Pole											
2	15.3										
4	28.0	33.1				3	27.6				
6	36.8	43.4	64.8			5	33.2	45.8			
8	19.9	23.5	35.2			7	39.2	54.2			
KW	0.795	0.870	0.950				0.815	0.913			
6 Slots Per Pole											
2	26.8					3	42.3				
4	46.4	63.4				5	57.7				
6	26.8	36.6									
KW	0.804	0.914					0.856				
4 Slots Per Pole											
2	60.8										
4	39.2										
KW	0.822										

worst. This condition exists when one end of the rotor bar lies under a north harmonic pole and the other end under a south harmonic pole. Since the seventeenth harmonic has 68 poles and the nineteenth has 76 poles the worst condition would be 1/68 times 44 equals 0.645 bar skew and 1/76 times 44 equals 0.58 bar skew.

Another condition that would not be good but which is better than the one just described is the existence of a 3-harmonic pole skew. This skew would be 3/68 times 44 equals 1.94 bars for the seventeenth harmonic and 3/76 times 44 equals 1.73 bars for the nineteenth harmonic. With this condition one end of the rotor bar would be under a north pole and the other end under a south pole. However, since the point one-third of the distance from the one would be under a pole of the same polarity as the beginning of the bar there would be a tendency to prevent a current flow in 2/3 of the bar.

Another factor to keep in mind when figuring skew is the effect of skew on the various modes of vibration of the frame as discussed by S. J. Wikina. There are 4 modes of vibration. The energy input per pole to the first, second, and fourth modes of vibration is zero with a skew of 1, 2, or any integral number of slot pitches. The maximum energy input with over one bar skew is never greater than 20 per cent of that with no skew. To eliminate the third mode of vibration it is necessary to have a skew of 1.43 bars or to have the number of rotor bars divisible by the number of poles. The energy is maximum at 2/3 bar skew. This is the most critical of the 3 modes rising rapidly on either side of the zero energy point. If, therefore, it is possible to eliminate the third mode of vibration by having the number of rotor bars divisible by the number of poles this third mode will be completely eliminated and the first and second will be lessened. Then by skewing the rotor one bar or more the first, second, and fourth modes will either be eliminated or made quite small. While I have never personally designed a quiet motor with this last method in mind, the engineer studying this paper will note that some of the designs discussed fulfill at least to some extent the requirements by meeting other requirements set forth in the earlier part of this work. The 44-bar rotor when used on a 4-pole motor is divisible by the number of poles. The same applies to the 20- and 34-bar rotors of the 2-pole motor. Since I never use less than one bar skew except on very short armatures other difficulties have been avoided.

In summarizing, there are some general statements that it is well to bear in mind.

1. Be sure the motor is built carefully in production.
2. The winding should be distributed so that all but 2 harmonics are eliminated.
3. The rotor should be skewed to eliminate these 2 harmonics and not less than one bar.
4. The number of rotor bars should be carefully selected so there will be no harmonics with a 2-pole difference. It may be advantageous to use a rotor with the number of bars divisible by the number of poles where necessary.
5. There should be no magnetic parts extremely light that will vibrate excessively. This especially refers to teeth and tooth tips.

Tables IV to XVI were calculated in 1917. They give the center ordinate value of the sinusoidal magnetomotive forces produced by a current of the instantaneous value of one ampere in a coil of 100 turns for the fundamental and all harmonics to the 33rd inclusive. The formula used for this calculation is:

$$h_m = \frac{4In_0}{m\pi} \times \sin\frac{m\pi}{2}\sin\frac{m\lambda\pi}{2}$$

in which

h_m is the center ordinate value of the mth harmonic
I is the value of the current at the given instant
n_0 is the number of turns per coil
m is the order of the harmonic
λ is the pitch expressed as a decimal fraction

The tabulated values are for a single coil. For distributed windings the resultant for the whole winding may be found as follows: For concentric windings, take from the tables the values for each of the coils separately, then add the respective values, with due regard to sign. The result will be the resultant of the whole winding. For diamond windings, multiply the tabular values for the center ordinate, by the expression

$$\frac{\sin\dfrac{m\pi}{2p'}}{\sin\dfrac{mp'}{2M_{sp}}}$$

in which p' is the number of phase belts per pole and M_{sp} is the number of slots per pole. The values of this factor are very easily calculated. This gives magnetomotive force per phase belt.

For single phase or 2-phase windings, concentric or diamond, the magnetomotive force per phase belt is also the magnetomotive force for the entire stator winding. For three-phase windings, the magnetomotive force for the entire winding is found by multiplying the magnetomotive force per phase belt by the factor $(p'/2)$ except for the harmonics whose number is divisible by 3, for which the factor zero is to be used; the latter harmonics are therefore not present in 3-phase windings.

This method was first published in *Electrical World*, August 26, 1909.

References

1. Quiet Induction Motors, L. E. Hildebrand. AIEE Transactions volume 49, July 1930, page 848.
2. Study of Noises in Electrical Apparatus, T. Spooner and J. P. Foltz. AIEE Transactions, volume 48, July 1929, page 747.
3. Synchronous Motor Effects in Induction Machines, E. E. Dreese. AIEE Transactions, volume 49, July 1930, page 1033.
4. Cusps in the Speed-Torque Curves of Induction Motors, P. H. Trickey. Electrical Engineering, December 1931, page 930.
5. Induction Motor Slot Combinations, G. Kron. AIEE Transactions, volume 50, June 1931, page 757.
6. Toward Quieter Motor-Driven Products, G. Kron. *Electrical Manufacturing*, November 1935.
7. Analysis of The Causes Of Noise And Vibration in Synchronous Machines, I. C. Benson. Thesis, University of Minnesota, 1934.
8. Effect of Skewing and Pole Spacing on Magnetic Noise in Electrical Machinery, S. J. Mikina. ASME *Transactions*, volume 56, October 1934, page 711.

A Formula for the Reactance of the Interleaved Component of Transformers

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THE REACTANCE of a power transformer is materially changed when connection is made to taps of different voltages. This can be computed for concentric, core-type transformers by dividing the winding into a concentric component and an interleaved component according to the method of H. O. Stephens.[1]

The concentric component is an assumed transformer winding in which the secondary ampere-turns are equal and opposite to the primary ampere-turns for each centimeter along the axis. The cylinder of winding of the actual transformer which has no part tapped out, is taken as one of the windings of the concentric component. The other winding of the concentric component matches the first exactly in ampere-turns per centimeter along the axis, magnetizing current being left out of consideration.

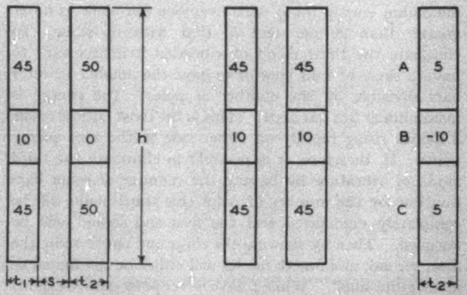
The interleaved component of winding is what is needed to be added to the concentric component to make the total equal to the actual transformer for the particular connection considered. Nothing needs to be added to the cylinder which has no part tapped out and so the interleaved component is a single cylinder. Its positive and negative ampere-turns are equal and opposite. See figure 1 and the descriptions in reference 1.

It is evident, from the simple rules just given by which the interleaved component is defined, that the number of ampere-turns of the parts of the interleaved component of winding, and their location, can be easily determined without any special formulas. Examples are clearly illustrated in reference 1. See also example I of this paper.

The leakage reactance X of a transformer when expressed in ohms is referred to either the primary side or the secondary. This is the same as finding the leakage reactance in ohms of a one-to-one ratio transformer. If I is the current of the side taken, the stored energy of the leakage magnetic field is I^2X and is equal to the summation of $H^2/8\pi$ for every cubic centimeter of the leakage magnetic field. Magnetizing current is taken equal to zero, or in other words the iron is assumed to have zero reluctance so far as the computation of leakage reactance is concerned.

If the primary and secondary of the one-to-one ratio transformer are connected in series and the current I is sent through them in the proper directions, the magnetic field will be the same as the leakage magnetic field, because it is produced by the same currents. $H^2/8\pi$ will be the same and the stored energy I^2X will be the same. But X is now $2\pi fL$ where L is the self-inductance of the complete circuit. This provides a method for computing X, which is used in the appendix.

Since the ampere-turns of the concentric and interleaved components are together equal to the ampere-turns of the actual transformer, the summation of $H^2/8\pi$ when both are carrying current gives I^2X for the transformer. The magnetic field of the concentric component is chiefly axial where the density is greatest and the most energy is stored, and the densest parts of the field of the interleaved component are radial. See figures 2 and 3, reference 1.



(a)—Actual transformer (b)—Concentric component (c)—Interleaved component

Figure 1. Cross section of core-type transformer winding

The fields of the 2 components are chiefly at right angles.

In any cubic centimeter, the stored energy of 2 fields H_1 and H_2 which are at right angles is $(H_1^2 + H_2^2)/8\pi$. As a consequence, the reactances of the concentric and interleaved components may be computed separately and added together to give, very nearly, the reactance of the tapped-out transformer. See the discussion by A. Boyajian, ELECTRICAL ENGINEERING (AIEE TRANSATIONS), 1934, page 1318. This has been shown to be a close approximation, by comparing the result with the transformer reactance computed by methods not involving the division into concentric and interleaved components. Tests on practical transformers also have shown the accuracy of the method. See the discussion by A. N. Garin, ELECTRICAL ENGINEERING (AIEE TRANSACTIONS), 1934, page 1319.

The study of interleaved components has shown that the reactance can be reduced and the eddy-current losses

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A paper recommended for publication by the AIEE committee on electrical machinery. Manuscript submitted July 12, 1937; released for publication September 30, 1937.

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[1] For all numbered references, see list at end of paper.

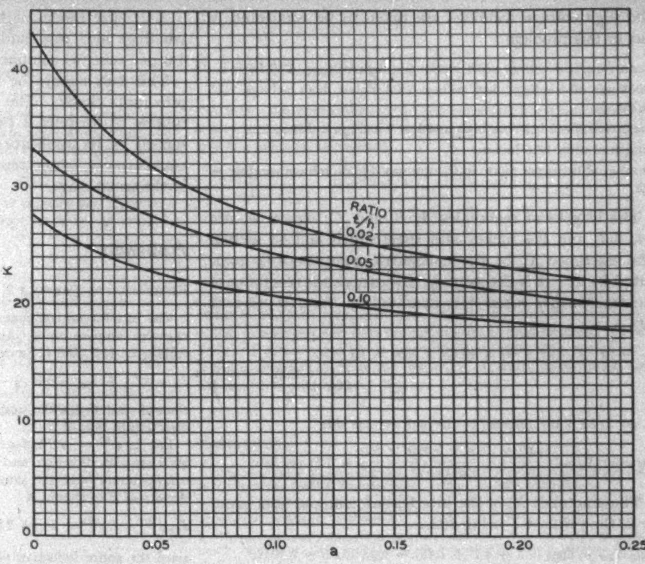

Figure 2. Curves for reactance of interleaved component

a = ratio of height of middle rectangle to h

$X_1 = KfmT^2 10^{-9}$ ohms per leg

in the copper minimized, by thinning out the turns in one winding opposite the tapped-out section of the other winding. See reference 1. This reduces the radial flux or "cross flux." The definition of interleaved component which has been given applies quite well to the case of thinned out transformer windings and so no special arrangements are necessary in the computation. All that is needed is to find the ampere-turns of the interleaved component and then the reactance of the 2 components of winding.

The paragraghs up to this point are a review of the material developed by H. O. Stephens in his paper.[1]

The leakage reactance of one leg of a concentric, core-type transformer without tapped-out sections is given very closely by the following well-known formula:[2]

$$X_c = \frac{8\pi^2 N^2 f m_1 10^{-9}}{h}\left(s + \frac{t_1}{3} + \frac{t_2}{3}\right) \text{ ohms} \qquad (1)$$

For the meaning of the letters see figure 1. Also, N is the number of turns of one cylinder of one winding, m_1 is the length of mean turn for the transformer, dimensions being in centimeters, and f is the frequency.

For the interleaved component of one leg of a core-type transformer which has one central tapped-out section, as shown in figure 1, find T, the number of turns in the tapped-out section in the interleaved component. See the third paragraph of this paper. Then, as derived in the appendix,

$$X_1 = \frac{4.605\pi f m T^2 10^{-9}}{a(1-a)^2}\,[(1+a)^2 \log_{10} S_{AB} - (1-a)^2 \log_{10} S_A - 2a \log_{10} S_B - 2a \log_{10} S_{ABC}] \text{ ohms} \qquad (2)$$

The rectangles A, B, and C are shown in figure 1c.

m = mean turn in centimeters of the interleaved component.

T = number of turns in B of the interleaved component.

a = ratio of the axial length of rectangle B to the length of the complete rectangle ABC.

S_{AB} = length + width, of the rectangle AB, and similarly for the other rectangles.

In figure 2, curves are given by which most of the computation of formula 2 may be avoided.

Formula 2 was derived in connection with thesis work at Massachusetts Institute of Technology.

Example I. The transformer shown in figure 1 has a tapped-out portion equal to 20 per cent of the secondary turns. Opposite this part, the primary winding has only 10 per cent of its turns, the winding being thinned out by spacing the individual coils farther apart. If N is the number of turns in one cylinder of the secondary winding when not tapped, then T for formula 2 is 0.1 N when operating on the 80-per-cent tap. When the transformer is operating on the 100-per-cent tap, the numerical value of T is also 0.1 N. The figures in figure 1 are percentages.

If the primary winding were not thinned out, then for operation on the 80-per-cent tap the value of T would be 0.2 N, and the increase in reactance would be 4 times as great, since it varies as T^2.

Example II. This utilizes the sample design of a 1,000-kva 575-to-13,800-volt 60-cycle transformer given on page 395 of "Design of Electrical Apparatus," by J. H. Kuhlmann.

The low-voltage winding is considered the primary. It is not thinned out. One-fifth of the turns of the high-voltage winding are tapped out, thus giving 11,000 volts.

The high-voltage windings are taken to be connected in star in this problem.

Mean turn, low voltage, 39.4 inches and high voltage, 53.9 inches.

Thickness of windings, low voltage 1.03 inches, high voltage 1.45 inches.

Insulation space between high and low windings, 1.063 inches.

Length of coils, 23.5 inches.

Number of turns per phase in the untapped high-voltage winding = 512.

The lengths of rectangles A, B, and C, figure 1c, are 9.4, 4.7, and 9.4 inches and their width is 1.45 inches. The reactance X_c of the concentric component is computed by 1. It is the same in this case as the reactance of the transformer when it is operated on the 100-per-cent tap.

$$X_c = 8\pi^2 \times 512^2 \times 60 \times 46.65 \times 2.54 \times 10^{-9} \times \frac{1}{23.5}\left(1.063 + \frac{1.03}{3} + \frac{1.45}{3}\right)$$

$= 11.83$ ohms, referred to the high-voltage side

$$\text{Per cent } X_c = \frac{11.83 \times 41.8 \times 1.732 \times 100}{13800} = 6.21 \text{ per cent}$$

The reactance X_i of the interleaved component is given by 2, the value of T being 102.

$$\log_{10} S_{AB} = \log_{10} (9.4 + 4.7 + 1.45) = \log_{10} 15.55 = 1.19173$$

Inch dimensions are permissible for S_{AB} etc. as described in the appendix.

$$\begin{aligned} \log_{10} S_A &= \log_{10} (9.4 + 1.45) = 1.0354 \\ \log_{10} S_B &= \log_{10} (4.7 + 1.45) = 0.7889 \\ \log_{10} S_{ABC} &= \log_{10} 24.95 = 1.3971 \\ a &= 0.2 \end{aligned}$$

$$X_i = 4.605\pi \times 60 \times 53.9 \times 2.54 \times 102^2 \times 10^{-9} \times \frac{1}{0.2 \times 0.64} \times [1.44 \times 1.19173 - 0.64 \times 1.0354 - 0.4 \times 0.7889 - 0.4 \times 1.3971] = 1.74 \text{ ohms}$$

This result can be obtained from figure 2, using $a = 0.2$, $t/h = 0.062$ and $K = 20.4$.

$$\text{Per cent } X_i = \frac{1.74 \times 41.8 \times 1.732 \times 100}{13800} = 0.91 \text{ per cent.}$$

Reactance of the tapped transformer $= 6.21 + 0.91 = 7.12$ per cent

Thus, the reactance is increased about one-seventh by tapping out the section.

The rated input to the tapped transformer is taken to be 1,000 kva at 575 volts, the same as for the untapped transformer, neglecting magnetizing current.

The way in which N and T are used, and the way in which reactance ohms are converted to percentages, should be noted, as the definitions for these items perhaps may be taken most easily from the example.

In order to make an approximate check of the calculations, a $^1/_4$-size model of the transformer coils was made. The reactance of the coils was measured without any iron core. In order to have the reactance larger than the resistance, 530-cycle current was used. The reactance then was corrected for 60-cycle current and for size. The result was 6.3 per cent for the tapped transformer, to compare with 7.12 per cent computed.

A $^1/_4$-size model of the interleaved component of the windings also was made and tested. Its reactance was 1.0 per cent, to compare with 0.91 per cent computed.

This test should be considered as a preliminary, approximate check. The question of the accuracy and usefulness of formula 2 presented in this paper should be settled by its application to the cases of practical power transformers, whose reactance has been accurately tested in the usual way.

Appendix

DERIVATION OF FORMULA 2

The interleaved component has the same number of positive as negative ampere-turns. Assuming that the windings of the 3 rectangles A, B, and C, figure 1c, are connected in series,

$$L_i = 2L_A + L_B - 4M_{AB} + 2M_{AC} \tag{3}$$

since A and C are the same size and their current is opposite in direction to that of B.

Let $L_{AB}^{(B)}$ = self-induction of A and B connected in series but with current direction and winding density in turns per square centimeter in both the same as in B. Let k = ratio of winding density of B to that of A.

$$L_{AB}^{(B)} = L_A^{(B)} + L_B + 2M_{AB}^{(B)} \tag{4}$$

since the entire inductive voltage drop in AB is made up of drop in A caused by its own current plus drop in B caused by its own current plus drop in A caused by current in B plus drop in B caused by current in A.

$$2M_{AB}^{(B)} = 2kM_{AB} = L_{AB}^{(B)} - k^2L_A - L_B$$

$$2M_{AB} = \frac{1}{k} L_{AB}^{(B)} - kL_A - \frac{1}{k} L_B \tag{5}$$

$$\begin{aligned} L_{ABC}^{(B)} &= 2L_A^{(B)} + L_B + 4M_{AB}^{(B)} + 2M_{AC}^{(B)} \\ &= 2L_{AB}^{(B)} - L_B + 2M_{AC}^{(B)} \end{aligned}$$

from 4.

$$2M_{AC} = \frac{2}{k^2} M_{AC}^{(B)} = \frac{1}{k^2} L_{ABC}^{(B)} - \frac{2}{k^2} L_{AB}^{(B)} + \frac{1}{k^2} L_B \tag{6}$$

From 3,

$$L_i = 2L_A + L_B - \frac{2}{k} L_{AB}^{(B)} + 2kL_A + \frac{2}{k} L_B + \frac{1}{k^2} L_{ABC}^{(B)} - \frac{2}{k^2} L_{AB}^{(B)} + \frac{1}{k^2} L_B$$

$$L_i = 2(1 + k)L_A + \left(1 + \frac{2}{k} + \frac{1}{k^2}\right) L_B + \frac{1}{k^2} L_{ABC}^{(B)} - \frac{2}{k}\left(1 + \frac{1}{k}\right) L_{ABC}^{(B)} \tag{7}$$

Turns in $B = T$
Turns in $A = T/2$
Turns in $AB^{(B)} = T + kT/2$
Turns in $ABC^{(B)} = T + kT$

$$L_A = 2m \frac{T^2}{4} \operatorname{logn} \frac{u}{G_A} \text{ abhenries}$$

$$L_B = 2mT^2 \operatorname{logn} \frac{u}{G_B} \text{ abhenries}$$

$$L_{AB}^{(B)} = mT^2 \frac{(2+k)^2}{2} \operatorname{logn} \frac{u}{G_{AB}} \text{ abhenries}$$

$$L_{ABC}^{(B)} = 2mT^2 (1+k)^2 \operatorname{logn} \frac{u}{G_{ABC}} \text{ abhenries}$$

where logn denotes natural logarithm, where u is a certain large distance to which flux is counted and which cancels out later, and where G_A is the self geometric mean distance of the rectangle A, and similarly for the other rectangles. This type of computation, which applies quite well for transformer reactance, deals with the reactance per centimeter of the circuit made up of the primary and secondary windings, and it is assumed that the effect of their curvature is negligible.

From 7,

$$L_t = mT^2(1+k) \operatorname{logn} \frac{u}{G_A} + 2mT^2\left(1+\frac{1}{k}\right)^2 \operatorname{logn} \frac{u}{G_B} +$$
$$2mT^2\left(1+\frac{1}{k}\right)^2 \operatorname{logn} \frac{u}{G_{ABC}} - mT^2\left(\frac{2+k}{k}\right)^2(1+k) \operatorname{logn} \frac{u}{G_{AB}} \quad (8)$$

From the definition of a following equation 2 and from the fact that the total turns in A, B, and C of the interleaved component are zero,

$$ka - (1-a) = 0$$

$$k = \frac{1-a}{a}$$

$$1 + k = \frac{1}{a}$$

$$1 + \frac{1}{k} = \frac{1}{1-a}$$

$$\left(\frac{2+k}{k}\right)^2 (1+k) = \frac{(1+a)^2}{a^2} \frac{a^2}{(1-a)^2} \frac{1}{a} = \frac{(1+a)^2}{a(1-a)^2}$$

A very close approximation[3] to the self geometric mean distance of a rectangular area is 0.2235 times (sum of sides). If this is used in 8, the following is obtained:

$$L_t = \frac{2.303mT^2}{a(1-a)^2}\left[(1+a)^2 \log_{10} S_{AB} - (1-a)^2 \log_{10} S_A - \right.$$
$$\left. 2a \log_{10} S_B - 2a \log_{10} S_{ABC}\right] \quad (9)$$

From this, 2 is directly obtained.

The coefficient of logn u in 8 is

$$1 + 2a + a^2 - (1 - 2a + a^2) - 4a$$

which is equal to zero, and so u cancels out. In the same way, 0.2235 cancels out and does not appear in the final formula. Also, if S_{AB}, etc., are given in inches, their multipliers 2.54 cancel out, but this does not apply to the dimension m, which must always be changed to centimeters.

References

1. TRANSFORMER REACTANCE AND LOSSES WITH NON-UNIFORM WINDINGS, H. O. Stephens. AIEE TRANSACTIONS, volume 53, 1934, page 346.

2. ELECTRICAL MACHINE DESIGN, A. Gray and P. M. Lincoln. Page 447, equation 65, and other textbooks.

3. FORMULAS AND TABLES FOR MUTUAL AND SELF-INDUCTION, E. B. Rosa and F. W. Grover. Sci. Paper 169 of the Bureau of Standards, equation (128), page 167.

"Inside a Metal"

CAREFUL RESEARCH into the nature of the metallic state has yet to discover, with any certainty, its essential quality, says L. R. van Wert, lecturer on metallurgy, Harvard University, Cambridge, Mass., in an article of the above title published in the October 1937 issue of *Mining and Metallurgy*, pages 453–8.

The basic fact underlying nearly all metallic behavior is that a metal is crystalline in its nature; any mass of metal that has been formed in the ordinary way is made up of many small crystals tightly bound together. It is true that a few properties, such as valence and ferromagnetism, are atomic in origin, so one must actually go within the atom for their ultimate source, but excepting these, metallic properties come about through varieties in interatomic organization.

All matter is atomic in nature, and the metals are no exception. However, with respect to the way the atoms are arranged matter is of 2 kinds: isotropic, of which liquids and gasses are examples; and crystalline, of which metals are examples. The crystalline state of matter is characterized, first, by a lower total energy than the isotropic form, and secondly, by the atoms being essentially at rest, and in regularly and definitely spaced positions. This regularity in atomic spacing confers on the crystal a definite internal architecture in which a certain pattern, often quite simple, is indefinitely repeated. This unit pattern is called the space lattice; the first word indicates that one is dealing with 3 dimensions, and the second suggests a rigid framework on which the atoms hang. The bonds are electrostatic in nature and electronic in origin.

It is not easy to create a simple physical picture of metal linkage [or bonding in metal], but in briefest outlines the picture is somewhat as follows: Because there are not sufficient valency electrons for the atoms to form groups among themselves by either the ionic or covalent manners of bonding, it becomes necessary for the electrons to act for several atoms. Like covalent bonding, metal linkage is one of electron sharing, but differs from it in that the sharing is really quite free and unrestricted. One may then "regard a metal not as an assembly of metal atoms, but rather as an array of positive metal ions held together by the attraction of intervening valence electrons." (Hume-Rothery, "The Structure of Metal and Alloys," page 17.) Or to put it differently, the crystal structure of metals may be looked upon as made up essentially of 2 interpenetrating lattices, one of positive metal ions, and the other exclusively of electrons.

These shared electrons, which are not the exclusive property of a particular atom, are responsible for many properties of the metal crystal other than its coherence and rigidity. Among these are such characteristic properties as electrical conductivity, thermionic emission, photoelectric phenomena, and a dozen or so thermo-magneto-electrical effects.

New Types of D-C Transformers

By C. C. HERSKIND
ASSOCIATE AIEE

This paper presents 2 new types of d-c transformers using grid-controlled mercury-arc rectifiers. These transformers perform the same function on a d-c system as does the usual transformer on an a-c system. One type of d-c transformer which is discussed has a constant-current output characteristic, while the other has a constant-potential output. The theory of operation and operating characteristics are described and oscillograms taken on a small unit are shown.

Introduction

FROM TIME to time various methods have been proposed for the purpose of transforming voltage on d-c systems without using a motor-generator set. Most of these schemes have employed some type of commutating device for interrupting the direct current; the interrupted current then being transformed by means of a transformer of the conventional type and finally again changed back into direct current by the commutating device. None of these schemes has proved practical, chiefly because of commutating difficulties with the interrupting device.

The use of thyratron tubes for the construction of a d-c transformer was proposed several years ago.[1] However, due in part to the limitations of the circuit then proposed, no applications have been made up to the present time.

This paper describes 2 new types of d-c transformers using grid-controlled mercury-arc rectifiers for commutating the direct current. The development of these d-c transformers is based upon a new circuit which was invented by Mr. C. A. Sabbah. This circuit operates upon an entirely new principle and possesses unique operating characteristics. It provides the commutating voltage, required for transferring current from winding to winding, which is essential to successful operation when using grid-controlled mercury-arc rectifiers. In addition, the circuit may also be used to change constant potential to constant current, as in the case of the constant-current d-c transformer.

The operation of the d-c transformer does not merely involve the conduction of current in succession through the several transformer windings. In order to accomplish this action, 2 requirements must be met, which influence directly the character of the circuit employed. These requirements are: First, magnetizing current must be supplied for exciting the core of the main transformer, and second, commutating voltage must be supplied for overcoming the counter electromotive forces which oppose the transfer of current from winding to winding. When grid-controlled mercury-arc rectifiers for commutating the current are used, further requirements must also be met; namely, sufficient commutating voltage must be supplied to provide a positive voltage on the anode, prior to conduction in order to obtain reliable pick-up, and to provide a negative voltage at the end of the conduction period for a sufficiently long time, in order to permit deionization of the anode; also the circuit action must be such that no attempt will be made to pass current through the circuit in the reverse direction during the anode conduction period.

Two types of d-c transformers, namely, the constant-current d-c transformer and the constant-potential d-c transformer, and their circuits and manner of operation, will be described. Oscillograms are included showing the wave forms obtained in actual operation.

The Constant-Current D-C Transformer

The operation of the constant-current d-c transformer will be described first, inasmuch as it serves best to illustrate the principles of operation whereby the commutating voltage is obtained from the combination of 3-phase transformer and 3 capacitors.

The schematic connection diagram of the constant-current d-c transformer is shown on figure 1. The transformer consists of:

1. A 3-phase transformer having 2 coils per phase.
2. Three capacitors, one connected across each phase of the transformer.
3. Six mercury-arc rectifier tubes for commutating the current.
4. Two d-c reactors, one in the input and the other in the output circuit, for maintaining a smooth current wave.

In addition a source of a-c power is required for exciting the grids of the tubes. (A pilot motor-generator set driven from the d-c supply may be used.)

Theory of Operation

The principle of operation may be best described by reference to the connection diagram figure 1, and the wave forms shown on figure 2. Referring to figure 2, let it be assumed that the grids of the primary and secondary anodes are excited from the pilot generator at a constant frequency, so that each secondary anode will fire before the primary anode on the corresponding leg of the transformer, by a time interval equal to α degrees. Then the primary and secondary anode current waves will be as shown by curves *a* and *b*, since it is assumed that there is sufficient reactance in series with the 2 d-c circuits so that the d-c currents are constant.

A paper recommended for publication by the AIEE committee on electrical machinery. Manuscript submitted February 10, 1937; released for publication September 17, 1937.

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[1] For numbered reference, see end of paper.

The capacitor current wave is fully determined if the primary and secondary anode current waves are known, as the capacitor must supply the current required to maintain the magnetomotive force in each transformer leg constant (neglecting magnetizing current). That this is the case will be evident if it is remembered that in a transformer, the primary and secondary ampere turns, neglecting magnetizing current, must be equal and opposite and that any current in a primary coil, which is not opposed by an equal and opposite current in the secondary coil, meets magnetizing reactance and generates a high voltage. Of course, there is no unidirectional component of current in the usual transformer, but this will not alter the validity of this requirement. The above principle is highly important, as the whole theory of operation of the constant-current d-c transformer is based upon the fact that the transformer magnetomotive force (neglecting magnetizing current) is maintained constant.

The average magnetomotive force in each transformer leg, during the whole cycle, is equal to the average of the magnetomotive forces due to the primary and secondary anode currents, each averaged over the cycle. In order to maintain this constant value of magnetomotive force on the transformer leg, the capacitor current must have the wave form shown by curve *c* on figure 2. The capacitor voltage wave is shown on curve *d*. The voltage is readily determined from the capacitor current as the current is constant during each interval.

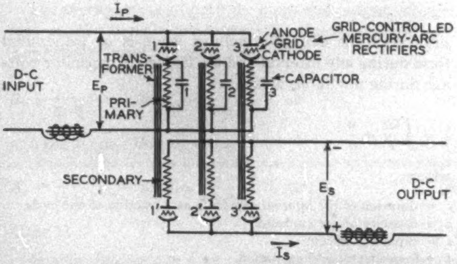
I_P
D-C INPUT
E_P
TRANS-FORMER
PRI-MARY
1
2
3
ANODE
GRID
CATHODE
GRID-CONTROLLED MERCURY-ARC RECTIFIERS
CAPACITOR
1
2
3
SECONDARY
E_S
D-C OUTPUT
1'
2'
3'
+
I_S

Figure 1. Connection diagram of constant-current d-c transformer

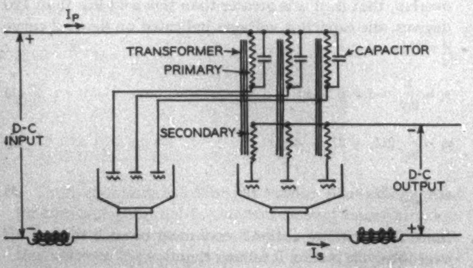
I_P
+
TRANSFORMER
PRIMARY
CAPACITOR
D-C INPUT
SECONDARY
D-C OUTPUT
+
I_S

Figure 1a. D-c transformer using 2 3-anode metal-tank grid-controlled mercury-arc rectifiers

The input and output voltages, curves *e* and *f*, are found by taking the capacitor voltages during the interval that the anode is conducting. The voltage will be supplied by any one phase only during the time that its anode is conducting. When the anode is not conducting, the voltage will be supplied from the other phases. The ripple in the d-c voltage wave is absorbed by the reactors in series with the 2 d-c lines. A clearer conception of the physical processes involved may be obtained if it is noted that during the interval t_1 to t_2, capacitor 1 is discharging into the output circuit. Its voltage falls as the secondary anode continues firing, until the secondary anode on the second phase is permitted to fire (by grid control), and the current transfers from anode 1′ to anode 2′, as capacitor 2 has a higher voltage than capacitor 1, and in the proper direction to force commutation. At t_3, the capacitor 1 is practically discharged, but now the primary anode on phase 1 is firing, and it is again being charged from the input circuit. At the end of the charging period, anode 2 is permitted to fire, and the input current is transferred from anode 1 to anode 2, as capacitor 2 has a lower counter electromotive force voltage than 1. During the period when neither primary nor secondary anode on phase 1 are firing, capacitor 1 discharges into the transformer winding, in order to maintain the required leg magnetomotive force,

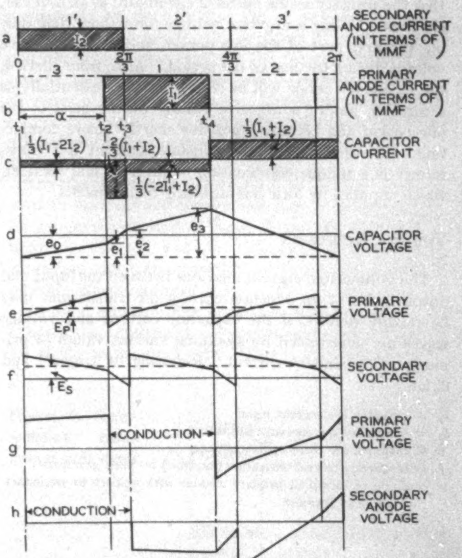
1'
2'
3'
SECONDARY ANODE CURRENT (IN TERMS OF MMF)
a
I_2
0
2π/3
4π/3
2π
3
1
2
PRIMARY ANODE CURRENT (IN TERMS OF MMF)
b
I_1
α
t_1
t_2
t_3
t_4
1/3(I_1-2I_2)
-2/3(I_1+I_2)
1/3(I_1+I_2)
1/3(-2I_1+I_2)
c
CAPACITOR CURRENT
d
e_0
e_1
e_2
e_3
CAPACITOR VOLTAGE
e
E_P
PRIMARY VOLTAGE
f
E_S
SECONDARY VOLTAGE
g
CONDUCTION
PRIMARY ANODE VOLTAGE
h
CONDUCTION
SECONDARY ANODE VOLTAGE

Figure 2. Constant-current d-c transformer wave forms. Case I—$\alpha >$ 0 degrees and $<$ 120 degrees

and reverses its polarity, so that it has the correct polarity to supply power to the output circuit, when it is again permitted to fire.

The anode voltages during the period when the anode is not conducting (that is, the anode-to-cathode voltages) may also be found from the capacitor voltages. They are shown by curves *g* and *h*. From curve *g* it will be noted that the primary anode operates essentially as an inverter, the anode having a negative voltage for a short time during the first part of the idle period, and then a positive voltage during the rest of the period. Also, from curve *h*, the secondary anode will be seen to operate essentially as a rectifier, having a negative voltage during most of the idle period and becoming positive shortly before conduction. In other words, the constant current d-c transformer is a unique combination of inverter and rectifier, which supplies its own commutating requirements.

Voltage Relations

The voltage and current relations between the input and output sides of the constant-current d-c transformer may be readily derived if the capacitor current and voltage waves are determined by assuming various values of primary and secondary current. Referring to figures 1 and 2, let

I_p = primary d-c current input
I_s = secondary d-c current output
n = ratio pri-sec turns on transformer
f = frequency of grid excitation (supplied by pilot generator)
α = angle of retard of primary anodes with respect to secondary anodes (degrees)
$k = \dfrac{\alpha}{120°}$

The average d-c component of the magnetomotive force on each leg of the transformer due to the anode currents is $^1/_3(I_1 + I_2)$, where I_1 is the magnetomotive force due to primary anode current I_p flowing in primary winding, that is, $I_1 = I_p$ times the number of primary turns, and I_2 is the magnetomotive force due to secondary anode current I_s flowing in secondary winding, that is, $I_2 = I_s$ times the number of secondary turns $= (I_s/n)$ times the number of primary turns. For simplicity the magnetomotive force may be expressed in terms of primary current, that is, $I_1 = I_p$ and $I_2 = I_s/n$.

In order to maintain the magnetomotive force on the transformer leg constant, the capacitor currents during the successive intervals will have the values indicated on curve *c* of figure 2.

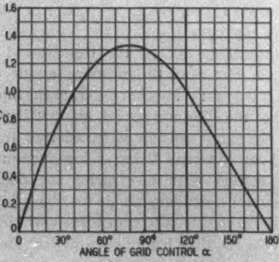

Figure 3. Value of functions ($4K - 3K^2$) and ($3 - 2K$)

Inasmuch as the capacitor current is constant during each interval due to the smoothing reactors in the input and output circuits, (if transformer magnetizing current is neglected) the capacitor voltage wave is of trapezoidal form during any interval and the change in capacitor voltage during any interval is

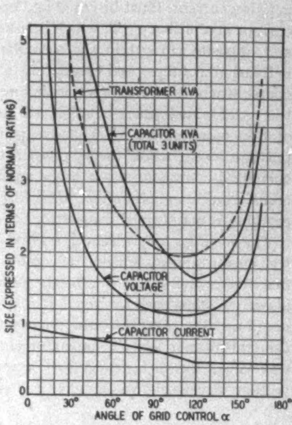

Figure 4. Size of capacitors and transformer

$$e = \int \frac{idt}{c} = \frac{it}{cf}$$

where

t = duration of the interval expressed as a fraction of one cycle
c = capacity of one capacitor
i = capacitor current
f = frequency of grid excitation

CASE I

If it is assumed that the conducting periods of the primary and secondary anodes connected to the same leg overlap, that is, if α is greater than zero and less than 120 degrees, the capacitor voltages indicated on figure 2 curve *d* will be:

$$e_1 = \frac{1}{9cf}[-I_1k + 2I_2k] \tag{1}$$

$$e_2 = \frac{1}{9cf}[2I_1 + 2I_2 - 3I_1k] \tag{2}$$

$$e_3 = \frac{1}{9cf}[2I_1 + 2I_2 - I_1k - I_2k] \tag{3}$$

Since the capacitor current wave must be such that $\int edt$ over the cycle is zero, it follows that

$$e_0 = \frac{1}{9cf}[I_1 + I_2 - I_1k] \tag{4}$$

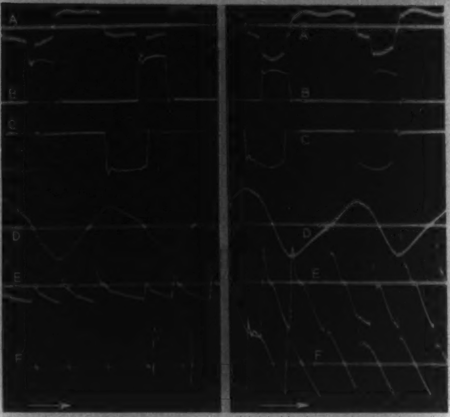

Figure 5. Oscillograms showing constant-current d-c transformer current and voltage wave forms

Curve *A*—Capacitor current
Curve *B*—Primary anode current
Curve *C*—Secondary anode current
Curve *D*—Capacitor voltage
Curve *E*—D-c input voltage
Curve *F*—D-c output voltage

The average value of both the input and output voltages may readily be calculated from these capacitor voltages. The average input voltage is then

$$E_p = \frac{1}{18\,cf}\,[4k - 3k^2]\,I_s = \frac{1}{18cf}\,[4k - 3k^2]\,\frac{I_s}{n} \qquad (5)$$

and the average output voltage is

$$E_s = \frac{1}{18\,cf}\,[4k - 3k^2]\,I_1 = \frac{1}{18\,cf}\,[4k - 3k^2]\,\frac{I_p}{n} \qquad (6)$$

CASE II

Similar expressions may be derived for the case where the conducting periods of the primary and secondary anodes do not overlap, that is, α is greater than 120 degrees and less than 180 degrees. The equations for the average input and output voltages when the anodes do not overlap, are, respectively,

$$E_p = \frac{1}{18\,cf}\,[3 - 2K]\,\frac{I_s}{n} \qquad (7)$$

and

$$E_s = \frac{1}{18\,cf}\,[3 - 2K]\,\frac{I_p}{n} \qquad (8)$$

These equations establish the voltage relations required for constant-potential-to-constant-current transformation. From the above expressions it will be noted that the relation between the voltage input and the current output may be changed in four ways, namely; first, by changing the grid phase angle between primary and secondary anodes; second, by changing the frequency; third, by changing the capacity; and fourth, by changing the transformer turn ratio between primary and secondary coils.

The constant-current d-c transformer may be operated with any angle of grid retard of the primary anodes with respect to the secondary anodes between the values zero and 180 degrees. The relation between the primary voltage and secondary current, as the angle of grid retard varies, is expressed by the functions $(4k - 3k^2)$ and $(3 - 2k)$, which are shown graphically on figure 3; with angles of grid retard at or near zero and 180 degrees, the secondary current becomes very large and is close to infinity for all values of impressed voltage. The characteristics of the transformer-capacitor combination under these conditions will be described in connection with the constant potential d-c transformer.

The effective values of the voltage and current appearing on the capacitors and transformer may be calculated from the relations indicated on figure 2, and the voltage equations (1), (2), (3), and (4). The calculated sizes of the capacitors and transformer for various angles of grid retard are shown on figure 4.

In the d-c transformer circuit, shown on figure 1, there exists a d-c component of magnetomotive force on each leg of the transformer core. This is apparent when it is

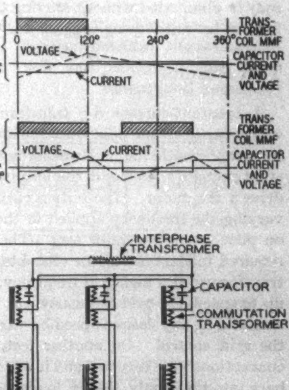
TRANS-FORMER COIL MMF
0
120°
240°
360°
a
VOLTAGE
α= 0°
CURRENT
CAPACITOR CURRENT AND VOLTAGE
TRANS-FORMER COIL MMF
b
VOLTAGE
CURRENT
α= 180°
CAPACITOR CURRENT AND VOLTAGE

Figure 6. Commutation transformer wave forms

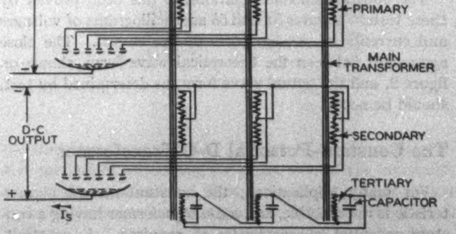
+
Ip
INTERPHASE TRANSFORMER
CAPACITOR
COMMUTATION TRANSFORMER
D-C INPUT
PRIMARY
–
MAIN TRANSFORMER
–
D-C OUTPUT
SECONDARY
TERTIARY
CAPACITOR
+
Is

Figure 7. Connection diagram of constant-potential d-c transformer

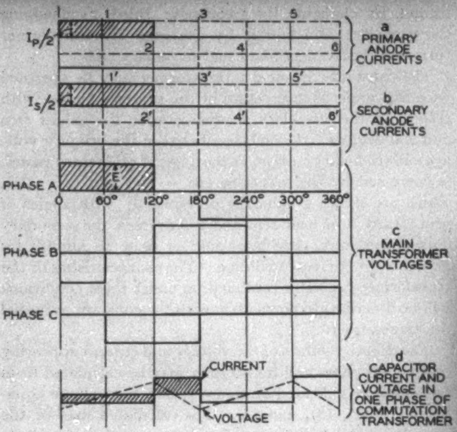

Figure 8. Constant-potential d-c transformer wave forms

noted that all currents entering the unit from the input side and leaving on the output side flow through the transformer coils in the same direction. This d-c component may be eliminated without altering the action of the transformer, by suitably zig-zagging the transformer coils.

Test Results

A constant-current d-c transformer of approximately 40-kw capacity has been tested in the factory. The tests were made with the d-c transformer connected to a constant-voltage source and the output current was used to drive a d-c motor. The output current was controlled by varying the frequency applied to the grids (speed control on pilot motor-generator set). The high output current required to start the motor was obtained by operating the transformer at a high grid frequency. As the motor came up to speed, the grid frequency was reduced. The motor was held at any desired speed by varying the frequency of the grid control. On another test, the d-c transformer connections were reversed and it was forced to pump power back into the supply, that is, to regenerate.

The constant-current relationship has been proved by these tests. Figures 5*a* and 5*b* are oscillograms of voltages and currents in various parts of the circuit. The close agreement between the theoretical wave form, shown on figure 2, and the actual wave form, as determined by test, should be noted.

The Constant-Potential D-C Transformer

For many applications, the constant-current characteristic is not suitable, and a d-c transformer having a constant-potential characteristic is required. A constant-potential d-c transformer may be constructed by making use of the transformer and capacitor combination, which has already been described in connection with the constant-current d-c transformer. In the case of the constant-potential transformer the transformer and capacitor combination is used to provide a commutating voltage and it will be referred to hereafter as the commutation transformer.

The commutation transformer consists of the transformer and capacitor combination used in the constant-current d-c transformer, with the angle of grid control between primary and secondary winding adjusted for either zero or 180 degrees. The capacitor current and voltage relations with angle of control equal to zero or 180 degrees are shown on figure 6. It should be noted that the capacitor voltage is directly proportional to the load current, so that the commutation transformer will furnish the required voltage at all loads to overcome the reactive voltages opposing transfer from winding to winding since these reactive voltages are proportional to the load.

Figure 9. Oscillogram showing constant-potential d-c transformer current and voltage wave forms

Curve *A*—Main transformer primary-coil voltage
Curve *B*—Primary anode current
Curve *C*—Secondary anode current
Curve *D*—Primary anode-to-cathode voltage
Curve *E*—Secondary anode-to-cathode voltage
Curve *F*—Commutating-transformer coil voltage

The schematic connection diagram of the constant-potential d-c transformer is shown on figure 7. Referring to this diagram, the constant-potential d-c transformer consists of (1) a 3-phase main transformer, having 2 primary coils, 2 secondary coils, and tertiary coil on each phase; (2) a commutation transformer having a 3-legged core with 2 coils per phase; (3) 3 capacitors, one connected across each phase of the commutation transformer; (4) an interphase transformer; (5) 3 capacitors, one connected across each tertiary coil on the main transformer; (6) 2 6-anode grid-controlled mercury-arc rectifiers, one connected to the primary windings of the main transformer and the other connected to the secondary windings of the main transformer.

The constant-potential d-c transformer consists essentially of a 6-anode inverter supplying power to the primary windings of the main transformer, and a 6-anode rectifier, receiving power from the secondary windings of the main transformer. The commutating voltage for transferring current from anode to anode on the inverter is supplied by the commutation transformer. The inverter is caused to operate as 2 3-anode circuits by means of the interphase transformer. The magnetizing current for the main transformer is supplied by the capacitors connected across the tertiary windings of the main transformer.

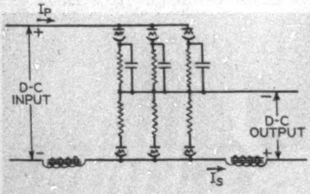

Figure 10. Diagram showing alternative connections for constant-current d-c transformer

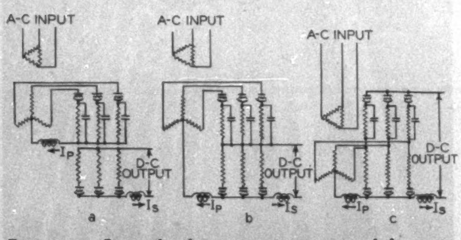

Figure 11. Circuits for changing constant-potential alternating current to constant-current direct current (single frequency)

The operation of the constant-potential d-c transformer will best be understood by referring to figure 8, which shows the wave form in the d-c transformer circuit. On figure 8 curves *a* and *b* show the primary anode current and secondary anode-current wave forms, respectively. It will be noted that each anode carries current for approximately 120 degrees. Curve *c* shows the transformer coil voltages on the different phases of the main transformer. Curve *d* shows the voltage supplied by the commutation transformer for effecting the transfer of current from anode to anode, and permitting deionization of the main anode, following the conduction period.

The voltage ratio of the constant-potential d-c transformer is determined by the winding ratio between primary and secondary coils on the main transformer. This voltage ratio is not susceptible to control by means of the grids, as in the case of the constant-current d-c transformer, and no control grids are required on the output rectifier.

Test Results

A constant-potential d-c transformer has been set up and tested in the factory, drawing power from a 500-volt d-c shop system, and driving a 250-volt d-c motor. The constant-potential d-c transformer was found to have a shunt voltage characteristic similar to that of an ordinary rectifier.

Figure 9 shows an oscillogram of the voltage and current in various parts of the constant-potential d-c transformer circuit.

Other Arrangements and Applications

Various arrangements of the combination of 3-phase transformer and 3 capacitors forming the constant-current d-c transformer are possible. Figure 10 shows an alternative method of connecting the input side of the constant-current d-c transformer. This connection has been shown to have the same constant-current characteristic as that of figure 1.

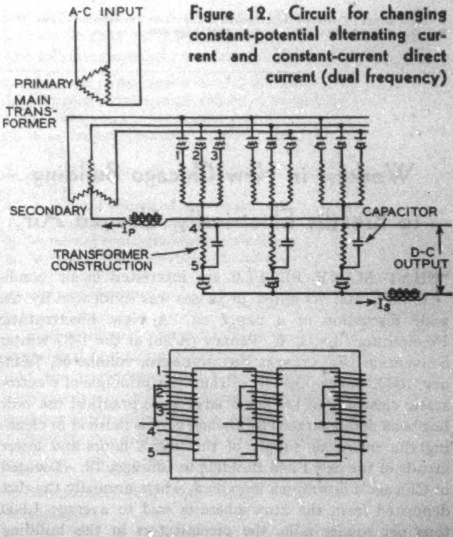

Figure 12. Circuit for changing constant-potential alternating current and constant-current direct current (dual frequency)

The constant-current d-c transformer circuit can also be used for changing constant-potential alternating current to constant-current direct current, that is, as a constant-current rectifier. Figure 11 shows 3 similar circuits of this type. In these circuits, the grids are excited at the same frequency as that of the a-c system. Figure 12 shows a circuit for changing constant-potential alternating current to constant-current direct current, in which the grids may be excited at a different frequency than that of the a-c system. The circuits shown in figures 11 and 12 may also be operated as inverters, that is, either changing constant-potential direct current to constant-current alternating current or changing constant-current direct current to constant-potential alternating current.

Conclusions

The general circuit and principles of operation which are described in this paper in connection with the constant-potential and constant-current d-c transformers, may also be applied to other rectifier circuits. Various arrangements of this general circuit utilizing a 3-phase transformer and 3 capacitors in combination with rectifier tubes, are possible. The new principles which have been described will undoubtedly prove useful in the development of apparatus for various rectifier applications, particularly those involving inverter operation.

Reference

1. The Direct Current Transformer Utilizing Thyratron Tubes, D. C. Prince. *General Electric Review*, July 1928, page 346.

Workers in New Chicago Building to Breathe Electrically Cleaned Air

THAT MANY PEOPLE are interested in air conditioning and its allied processes was evidenced by the wide discussion of a paper on "A New Electrostatic Precipitator" by G. W. Penney (A'26) at the 1937 winter convention (Electrical Engineering, volume 56, January 1937, pages 159–63). That the principle of electrostatic cleansing of air has a large-scale practical use now has been demonstrated by the use of this method in cleaning the entire air supply of the first 4 floors and lower arcade of the new Field Building in Chicago, Ill. Located in Chicago's downtown loop area, where annually the dirt deposited from the atmosphere is said to average 1,000 tons per square mile, the precipitators in this building supply more than 16 million cubic feet of cleaned air per hour.

Dust particles so small that they pass through any ordinary mechanical filter are readily removed by means of electrostatic precipitation. By this process impurities are taken from the air not by sifting them out mechanically, but by charging the particles electrically and withdrawing them as they pass through an electrostatic field. The air is first ionized by passing it through a maze of grounded cylinders and fine wires; the wires, charged to a negative potential of 12,000 volts, are only 0.005 inch in diameter and of course cannot be seen in the photograph of the intake side of one of the Field Building precipitators shown on this page. After the solid particles have been charged, the treated air next is drawn through a series of cells consisting of alternately spaced high-potential and grounded plates, the charged particles of impurities adhere to the plates, and the air so freed of solid matter passes on through ducts that lead to the areas being served by the equipment. Each cell of the Chicago system contains 111 plates 8 by 9 inches in size, and nearly half a mile of the fine tungsten ionizing wire was used in the construction of the 369 cells. The high-potential precipitator plates are charged to a positive potential of 5,000 volts.

Particles having diameters smaller than 0.0025 inch pass readily through 200-mesh screens of mechanical filters. These particles ordinarily are invisible, except in rays of bright light, but are extremely coarse in comparison with the atmospheric dust particles that fill the air of a busy city. The average solid particle in cigarette smoke has a diameter of only 0.0000039 inch. Enlarged 250,000 times, the larger particles that pass through a 200-mesh screen would be 50 feet in diameter; an average atmospheric dust particle would appear as big as a baseball; but at the same magnification the average cigarette-smoke particle would be a little more than an inch in diameter, or slightly smaller than a golf ball.

Load Loci for Transformers in Parallel

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MEMBER AIEE

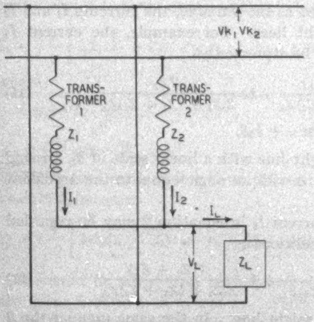
Abstract

The method of circular loci is applied to the problem of 2 transformers operating in parallel. It is shown that with comparatively little computation the variation of current in either transformer or the ratio of the 2 currents may be obtained as a function of the load impedance or the ratio of transformation. A numerical problem is given to illustrate a typical application.

Introduction

THE OPERATION of 2 transformers in parallel under ideal conditions assumes equal percentage resistances and reactances and equality of high-tension and low-tension voltages, neglecting excitation currents. Frequently it is necessary to connect in parallel transformers which do not conform to the ideal requirements. It is then necessary to change the ratio of transformation of one of the transformers to prevent overloading. The problem of parallel operation of transformers has been treated by many investigators, references to several being given at the end of this paper.[1-5]

Figure 1



When confronted simultaneously with several variables, involved in parallel operation, such as load impedance, load power factor, tap position and internal impedance, the author has found the method of circular loci to be convenient and time saving for determining the variation of transformer currents as a function of any of the variables present. This method is the only alternative to the laborious and time-consuming point-by-point solution of expressions with complex coefficients.

This paper develops the application of circular loci to the determination of currents and current ratios for the general case of 2 transformers connected in parallel. It is shown how, with comparatively little computation, a circular locus may be plotted which gives directly the magnitude and phase angle of the desired unknown as the variable passes through its complete range, from minus infinity or zero to plus infinity.

General Equations for Parallel Operation

In figure 1 are shown 2 transformers, numbered 1 and 2, respectively, connected in parallel and supplying a load Z_L. The equivalent circuits of the transformers are assumed to be reduced to the low-tension side. The exciting admittances are considered to be negligible and the elements of the circuits are assumed to be linear. The load impedance, Z_L, may have any phase angle and its magnitude may vary from short circuit to open circuit. The following symbols will be used throughout the paper:

I_1 = current in low-tension winding of transformer 1
I_2 = current in low-tension winding of transformer 2
I_L = load current in low-tension side
Z_1 = equivalent impedance of transformer 1 referred to low-tension side
Z_2 = equivalent impedance of transformer 2 referred to low-tension side
V = terminal voltage on high-tension side
V_L = terminal voltage on low-tension side
k_1 = ratio of transformation of transformer 1
k_2 = ratio of transformation of transformer 2

$$\text{ratio of transformation} = \frac{\text{induced voltage in low-tension winding}}{\text{induced voltage in high-tension winding}}$$

The problem to be considered is the behavior of the individual transformer currents, I_1 and I_2, as Z_L varies and the transformer ratios, k_1 and k_2, remain constant; also the variation of transformer currents when Z_L is fixed and one of the ratios, k_1 or k_2, varies.

Writing the voltage drops in the 2 circuits

$$V_L = Vk_1 - I_1Z_1 = Vk_2 - I_2Z_2$$

and eliminating the load voltage and current by the relationships:

$$I_L = \frac{V_L}{Z_L} \text{ and } I_L = I_1 + I_2$$

the equations may be solved for I_1 and I_2 giving

$$I_1 = V\frac{k_1Z_2 + (k_1 - k_2)Z_L}{Z_1Z_2 + (Z_1 + Z_2)Z_L} \tag{1}$$

$$I_2 = V\frac{k_2Z_1 - (k_1 - k_2)Z_L}{Z_1Z_2 + (Z_1 + Z_2)Z_L} \tag{2}$$

A paper recommended for publication by the AIEE committee on power transmission and distribution. Manuscript submitted July 12, 1937; released for publication September 21, 1937.

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1. For all numbered references, see list at end of paper.

Both expressions for current are linear in numerator and denominator with respect to all the circuit constants Z_1, Z_2, Z_L, k_1, and k_2.

The canonical form of a circle, written as a linear fractional transformation is

$$S = \frac{\alpha + \beta\rho}{\gamma + \delta\rho} \tag{3}$$

Here S is a vector whose extremity follows a circle as the scalar variable ρ varies from minus to plus infinity and α, β,γ,δ are complex constants.[6]

It is evident that the transformer currents follow circular loci when any one of the circuit constants be considered as the variable, because in each case both numerator and denominator can be written in the form of a constant term plus a constant times the variable scalar, giving thereby the equation of a circle.

That the transformer currents follow circular loci could also have been realized immediately from the theorem of circularity for a general network which states: "that in a network containing any number of linear and bilateral self- and mutual-impedance elements connected in any manner, with constant sinusoidal electromotive forces of like frequency connected in any arm, all currents and all voltages follow circular loci when any one impedance is varied along a straight line in the complex plane."[7] Thus, if any one of the circuit impedances be considered to vary at constant power-factor both transformer currents will follow circular loci.

Loci of I₁ and I₂ With Variable Z_L

With the load impedance Z_L assumed to be the variable the equation for I_1 is written as

$$I_1 = V\frac{k_1Z_2 + (k_1 - k_2)1\angle\theta_L\,|Z_L|}{Z_1Z_2 + (Z_1 + Z_2)1\angle\theta_L\,|Z_L|} \tag{4}$$

Here the variable Z_L has been put in the form

$$Z_L = |Z_L|\,\epsilon^{j\theta_L} = 1\angle\theta_L\,|Z_L| \tag{5}$$

where θ_L is the phase angle of Z_L and $|Z_L|$ is the magnitude of Z_L. In this way the scalar variable ρ of the canonical form becomes $|Z_L|$ and the phase angle of Z_L becomes part of the complex constant δ.

The constants of the canonical form for I_1 are then:

$$\left.\begin{aligned} \alpha &= Vk_1Z_2 & \gamma &= Z_1Z_2 \\ \beta &= V(k_1 - k_2)1\angle\theta_L & \delta &= (Z_1 + Z_2)1\angle\theta_L \\ \rho &= |Z_L| \end{aligned}\right\} \tag{6}$$

The invariant points, that is the values of I_1 for $|Z_L| = 0$ and $|Z_L| = \infty$ are

$$\left.\begin{aligned} I_{1(0)} &= V\frac{k_1}{Z_1} \quad \text{(short circuit)} \\ I_{1(\infty)} &= V\frac{k_1 - k_2}{Z_1 + Z_2} \quad \text{(open circuit)} \end{aligned}\right\} \tag{7}$$

In the same manner the current in transformer 2 is written as

$$I_2 = V\frac{k_2Z_1 - (k_1 - k_2)1\angle\theta_L\,|Z_L|}{Z_1Z_2 + (Z_1 + Z_2)1\angle\theta_L\,|Z_L|} \tag{8}$$

The constants in this case are:

$$\left.\begin{aligned} \alpha &= Vk_2Z_1 & \gamma &= Z_1Z_2 \\ \beta &= -V(k_1 - k_2)1\angle\theta_L & \delta &= (Z_1 + Z_2)1\angle\theta_L \\ \rho &= |Z_L| \end{aligned}\right\} \tag{9}$$

The invariant points are:

$$\left.\begin{aligned} I_{2(0)} &= V\frac{k_2}{Z_2} \quad \text{(short circuit)} \\ I_{2(\infty)} &= -V\frac{k_1 - k_2}{Z_1 + Z_2} \quad \text{(open circuit)} \end{aligned}\right\} \tag{10}$$

The internal impedances Z_1 and Z_2 used in the equations should correspond to the particular transformer ratios k_1 and k_2 associated with them. In certain problems it is desired to study load sharing when either ratio k_1 or k_2 is changed. For a theoretically correct solution of such a problem it would be necessary to know the variation of internal impedance corresponding to each tap on the transformer. If such data are available, the proper values of Z_1 and Z_2 appropriate to the particular tap positions being used should be employed in the equations.

If the problem involves small changes in ratio from the one pertaining to the value of internal impedance used in the equations, it is frequently permissable, for the degree of accuracy desired in the results, to consider the internal impedance a constant as the ratio is changed slightly.

With this assumption the construction of a family of circles, considering the transformation ratio k_1 or k_2 as the parameter, is greatly simplified. The ratios k_1 and k_2 occur only in the numerators of the expressions for transformer currents. If, for the moment, the load impedance Z_L and one of the ratios, as k_1 be assumed fixed, and the ratio k_2 be assumed as the variable, the currents I_1 and I_2 will follow straight lines. For example, the current I_1 in equation 1 may be expressed as

$$I_1 = \frac{Vk_1(Z_2 + Z_L)}{Z_1Z_2 + (Z_1 + Z_2)Z_L} - k_2\frac{VZ_L}{Z_1Z_2 + (Z_1 + Z_2)Z_L} \tag{11}$$

which is of the form $\alpha + k_2\beta$.

This is a straight line with a linear scale in k_2, passing through the point α with an angle equal to the argument of β.

Similarly the current I_2 in equation 2 may be regarded under the same conditions as

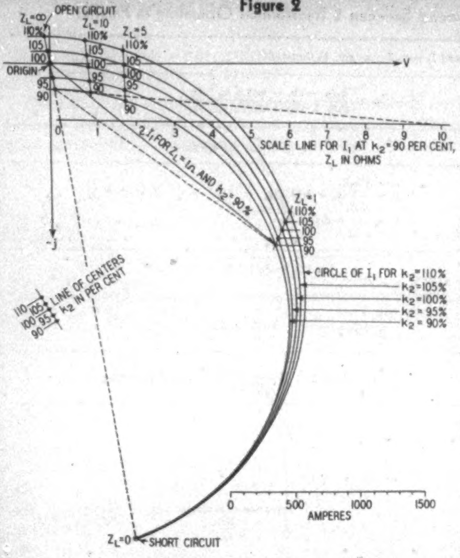
$$I_2 = \frac{-Vk_1Z_L}{Z_1Z_2 + (Z_1 + Z_2)Z_L} + k_2\frac{V(Z_1 + Z_L)}{Z_1Z_2 + (Z_1 + Z_2)Z_L} \tag{12}$$

This is another straight line. In the same manner the 2 equations for currents may be regrouped with respect to k_1 as the variable. These straight-line relationships facilitate the plotting of a family of circles with either transformer ratio as the parameter and the load impedance as the variable. For instance, 2 circles are drawn with the load impedance as the variable for 2 different values of k_2. Points on these circles for equal values of Z_L are then connected by straight lines. The interval of k_2 between such pairs of corresponding points may then be used as a scale of k_2 to spot points on circles for other values of k_2.

The vector to the center of a circle is[6]

$$C = \frac{\alpha\bar{\delta} - \beta\bar{\gamma}}{\gamma\bar{\delta} - \delta\bar{\gamma}} \tag{13}$$

Figure 2



in which the vinculum ($^-$) indicates the conjungate of the vector to which it is attached.

Substituting the constants given in equations 6 the center vector C_1 to the center of the circle for I_1 is

$$C_1 = j\,\frac{V}{Q}\left[k_1Z_2\overline{(Z_1+Z_2)}1\angle-\theta_L - (k_1-k_2)1\angle\theta_L\overline{(Z_1Z_2)}\right] \tag{14}$$

where

$$\left.\begin{aligned} Q &= 2(R'X'' - R''X') \\ Z_1Z_2 &= R' + jX' \\ (Z_1+Z_2)1\angle\theta_L &= R'' + jX'' \end{aligned}\right\} \tag{15}$$

Similarly the center vector C_2 to the center of the circular locus of I_2 becomes

$$C_2 = j\,\frac{V}{Q}\left[k_2Z_1\overline{(Z_1+Z_2)}1\angle-\theta_L + (k_1-k_2)1\angle\theta_L\overline{(Z_1Z_2)}\right] \tag{16}$$

It should be noted that both center vectors C_1 and C_2 are linear functions of k_1 and k_2. Thus if the families of circles for I_1 and I_2 are drawn with Z_L as the variable and either k_1 or k_2 as the parameter, the centers of the circles for both families will lie on straight lines whose equations are C_1 and C_2, respectively. Furthermore the distances between the centers of the circles will be proportional to the increments of the parameter k_1 or k_2.

The radius of a circle is given by the expression[8]

$$R = \left|\frac{\alpha\delta - \beta\gamma}{\delta\bar{\gamma} - \gamma\bar{\delta}}\right| \tag{17}$$

Substituting the transformer constants into the above equation, the radius R_1 for the locus of I_1 is

$$R_1 = \left|\frac{VZ_2}{Q}\left[Z_1(k_1-k_2) - k_1(Z_1+Z_2)\right]\right| \tag{18}$$

Similarly the radius R_2 for the locus of I_2 is

$$R_2 = \left|\frac{VZ_1}{Q}\left[Z_2(k_1-k_2) + k_2(Z_1+Z_2)\right]\right| \tag{19}$$

The expressions for the 2 radii R_1 and R_2 are likewise linear with respect to k_1 and k_2. Thus if the radii of 2 circles for different values of transformer ratio are known, the difference between these 2 radii may be used as a linear scale for obtaining radii for other values of transformer ratio.

Hence, to obtain a plot of a family of circles of transformer current with variable load impedance and one of the transformer ratios as the parameter, it is necessary to employ the analytical expression for only 2 of the circles; the linear relationships between corresponding points on different circles and between the centers of the circles suffice to locate other circles and points thereon, for any desired values of k_1 or k_2.

A circular locus may be determined by calculating 3 points on its periphery from the analytical expression or by computing the center vector and the radius. The 3-point method generally involves less computation because 2 of the points used for location are the invariant points which reduce the expression from the quotient of the sums of 2 complex terms to a quotient of 2 complex terms only. For the third point any convenient value of Z_L may be chosen. In this manner the entire analytical expression need be used only once, namely, for the calculation of the third point.

The third point is also used in conjunction with the invariant points for the determination of the linear scale line. This scale line is any line drawn perpendicular to the line joining the center of the circle and the point on the circle corresponding to $I_{1(\infty)}$, the open-circuit point. The intersections of the scale line, drawn in this manner, with lines joining points on the circle at which Z_L is known and the open-circuit point, determine a linear scale of Z_L on the scale line. Any chord then drawn through the open-circuit point and intersecting the scale line, connects corresponding points of Z_L on the scale line and on the circle.

If, for example, it is desired to plot a family of circles of I_1 with the ratio of the transformer 2, k_2, as the parameter, the 3-point method is employed to locate 2 circles for 2 different values of k_2. The center vectors and the radii of these circles may be computed to check the results. Scale lines are then drawn for both circles and as many points of I_1 as desired are spotted on the 2 circles. Corresponding points of I_1 (for equal values of Z_L) are then joined with straight lines. The intervals on the connecting lines are then linearly subdivided to form a convenient scale of k_2. These scales are then projected at both ends of the connecting lines, thereby giving points on other circles for the same values of Z_L. A straight line through the centers of the 2 circles is similarly subdivided and extended with a scale of k_2 thus locating the center points of circles for other values of k_2.

With k_2 as the parameter of the I_1 circles, the short-circuit point $L\,I_{1(0)} = Vk_1/Z_1$ is common to all the circles and the open-circuit point follows the straight line,

$$I_{1(\infty)} = V\,\frac{k_1-k_2}{Z_1+Z_2}$$

Table I. Equations and Constants for Division of Currents Between 2 Transformers Operating in Parallel

Conditions	Variation of I_1 and I_2 with Z_L; k_1 and k_2 Constant	
Equation	$I_1 = V\dfrac{k_2Z_2 + (k_1 - k_2)1\angle\theta_L\,\lvert Z_L\rvert}{Z_1Z_2 + (Z_1 + Z_2)1\angle\theta_L\,\lvert Z_L\rvert}$	$I_2 = V\dfrac{k_2Z_1 - (k_1 - k_2)1\angle\theta_L\,\lvert Z_L\rvert}{Z_1Z_2 + (Z_1 + Z_2)1\angle\theta_L\,\lvert Z_L\rvert}$
Locus	Circle	Circle
Circle constants and invariant points	$\alpha = Vk_1Z_2$ $\beta = V(k_1 - k_2)1\angle\theta_L$ $\gamma = Z_1Z_2$ $\delta = (Z_1 + Z_2)1\angle\theta_L$ $\rho = \lvert Z_L\rvert$ $I_{1(0)} = \dfrac{Vk_1}{Z_1}$ $I_{1(\infty)} = V\dfrac{k_1 - k_2}{Z_1 + Z_2}$	$\alpha = Vk_2Z_1$ $\beta = -V(k_1 - k_2)1\angle\theta_L$ $\gamma = Z_1Z_2$ $\delta = (Z_1 + Z_2)1\angle\theta_L$ $\rho = \lvert Z_L\rvert$ $I_{2(0)} = V\dfrac{k_2}{Z_2}$ $I_{2(\infty)} = -V\dfrac{k_1 - k_2}{Z_1 + Z_2}$
Denominator constants for center and radius	Let $Z_1Z_2 = R' + jX'$; Let $Q = 2(X''R' - X'R'')$	Let $(Z_1 + Z_2)1\angle\theta_L = R'' + jX''$;
Radius	$\left\lvert \dfrac{VZ_2}{Q}[Z_1(k_1 - k_2) - k_1(Z_1 + Z_2)] \right\rvert$	$\left\lvert \dfrac{VZ_1}{Q}[Z_2(k_1 - k_2) + k_2(Z_1 + Z_2)] \right\rvert$
Center vector	$\dfrac{jV}{Q}[k_1Z_2(\overline{Z_1 + Z_2})1\angle -\theta_L - (k_1 - k_2)1\angle\theta_L(\overline{Z_1Z_2})]$	$\dfrac{jV}{Q}[k_2Z_1(\overline{Z_1 + Z_2})1\angle -\theta_L + (k_1 - k_2)1\angle\theta_L(\overline{Z_1Z_2})]$
Definitions	Z_1 = equ. ohmic imp. of Trans. 1, referred to L. T. side Z_2 = equ. ohmic imp. of Trans. 2, referred to L. T. side Z_L = load imp. in ohms, in L. T. side θ_L = phase angle of Z_L $\lvert Z_L\rvert$ = magnitude of Z_L I_1 = current in L. T. wdg. of Trans. 1 I_2 = current in L. T. wdg. of Trans. 2 k_1 = ratio of transformation of Trans. 1 k_2 = ratio of transformation of Trans. 2 Ratio of transformation = $\dfrac{\text{Ind. voltage in L. T. wdg.}}{\text{Ind. voltage in H. T. wdg.}}$ I_L = load current = $I_1 + I_2$ V = terminal voltage on H. T. side	Equation of a circle $S = \dfrac{\alpha + \beta\rho}{\gamma + \delta\rho}$ vinculum (¯) represents conjugate

A family of I_2 circles with either transformer ratio as the parameter is constructed similarly. It should be observed that if k_2 be taken as the parameter, k_2 occurring in both invariant points of I_2 (see equation 10), the short-circuit point follows the line $I_{2(0)} = Vk_2/Z_2$ and the open-circuit point follows the line

$$I_{2(\infty)} = -V\frac{k_1 - k_2}{Z_1 + Z_2}$$

Although any values of k_1 or k_2 may be used to obtain a family of I_1 and I_2 circles, it should be remembered that the circles used for final results should not pertain to values of k_1 or k_2 far enough away from the values of these ratios which apply to the internal impedances used in the parametric expressions of the circles, to vitiate the approximation that the internal impedances remain constant. Otherwise it is not possible to draw a family of curves as described above and a separate expression must be set up for each circle with values of Z_1 and Z_2 corresponding to the particular values of k_1 and k_2 desired.

If the expressions for I_1 and I_2, equations 1 and 2, be divided one by the other, a convenient relationship for the ratio of load currents I_1/I_2 results. This is

$$\frac{I_1}{I_2} = \frac{k_1Z_2 + (k_1 - k_2)Z_L}{k_2Z_1 - (k_1 - k_2)Z_L} \qquad (20)$$

This equation is linear in both numerator and denominator with respect to all variables and therefore follows a circular locus with Z_L, k_1, or k_2 considered as the variable. The construction of the circular loci of I_1/I_2 may be carried out in the same manner as indicated for the individual loci of I_1 and I_2.

For convenience in reference the various equations and constants necessary for the cases treated above have been grouped together in chart form and tabulated in table I.

With the analysis that has just been presented, the engineer has at his disposal a complete set of equations which permits ready plotting of the currents or current ratios for parallel transformer operation, as a function of any of the variables encountered in practice.

Numerical Example

To illustrate the application of this method to a typical problem, the circular loci of I_1 and I_2 will be determined for the following 2 transformers:

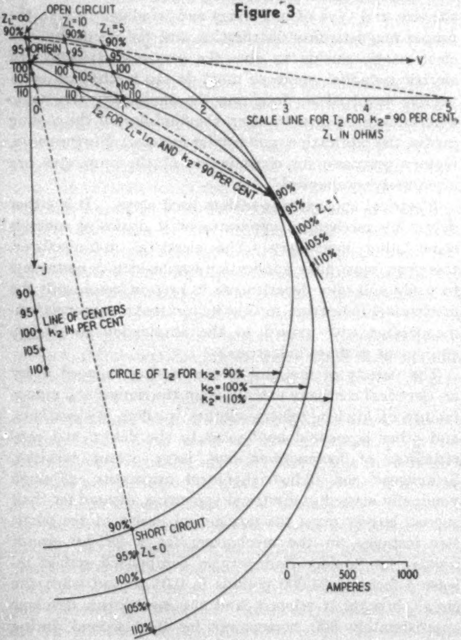
	Transformer 1	Transformer 2
High-tension terminal voltage	33,000 volts	33,000 volts
Low-tension terminal voltage at open circuit	6,600 volts	6,600 volts
Rating	3,000 kva	1,500 kva 3,000 kva
Rated low-side current	455 amperes	227.5 amperes
Percentage leakage reactance	12 per cent	5 per cent
Percentage resistance	2 per cent	1 per cent
Percentage impedance	12.2 per cent	5.1 per cent
Equivalent impedance reduced to low side	0.2915 + j1.745 ohms 1.77∠80.5° ohms	0.289 + j1.45 ohms 1.48∠78.7° ohms
Transformer ratio k	0.2	0.2

The load will be taken at unity power factor. Then $Z_L = 1\angle 0^\circ\,|Z_L|$

$$Z_1Z_2 = -2.44 + j0.926 = 2.61\ \angle 159.2^\circ$$
$$Z_1 + Z_2 = 0.5805 + j3.195 = 3.24\ \angle 79.7^\circ$$

The loci of the individual transformer currents will be obtained for the ratios $k_1 = k_2 = 0.2$ as given above. The ratio of 0.2 will be considered as 100 per cent. To indicate how readily a family of circles can be plotted with the assumption that the change in internal impedance may be neglected for small changes in ratio, the ratio k_1 will be kept constant and the ratio k_2 will be treated as a parameter for the family. The high-tension terminal voltage V will be taken as the reference vector throughout.

Figure 3



Locus of I_1

Inserting the constants into equation 4 the current I_1 in transformer 1 becomes

$$I_1 = 33{,}000\,\frac{0.2(0.289 + j1.45) + (0.2 - k_2)\,|Z_L|}{(-2.44 + j0.926) + (0.5805 + j3.195)\,|Z_L|} \qquad \textbf{(21)}$$

Two circles will be determined, for $k_2 = 0.18$ and 0.20, that is for ratios of 90 and 100 per cent, respectively, for transformer 2. The circles will be plotted by obtaining the invariant points and one other point on each, which in this case will be taken at $Z_L = 1$ ohm. The 2 sets of points for the circles are as shown in table II.

The 2 circles as determined by these points are drawn in figure 2. Straight lines are drawn connecting points of equal load impedance on the 2 circles. The intervals on these lines are used as scales for locating corresponding points on circles for k_2 = 95, 105, and 110 per cent. A straight line is drawn through the center points and the interval on this line is employed as a scale for obtaining the centers of the other circles. A scale line is drawn for the 90-per-cent circle. The value of I_1, in magnitude and phase, for any value of Z_L, is obtained by placing a straight edge on the infinity point and the desired value of Z_L on the scale line. The intersection of the straight edge with the circle is then the extremity of the vector I_1 for the particular value of Z_L. A similar scale line may be drawn for another circle and points of I_1 for various values of Z_L spotted on it. Straight lines connecting corresponding points on these circles suffice to locate corresponding points of I_1 on the other circles. Such lines are shown for Z_L = 5 and 10 ohms. A scale line was drawn for the 110-per-cent circle for this purpose, but it is omitted in the figure for the sake of clarity.

Table II

Z_L	I_1 Amperes	
	k_2 = 90 Per Cent	k_2 = 100 Per Cent
0	$3{,}730\ \angle -80.5^\circ$	$3{,}730\ \angle -80.5^\circ$
1	$2{,}195\ \angle -39.4^\circ$	$2{,}160\ \angle -35.6^\circ$
∞	$203.5\ \angle -79.7^\circ$	0

To verify the construction the center vectors and the radii of the 2 circles may be calculated. From equations 15 the constant Q is

$$Q = 2[-3.195 \times 2.44 - 0.926 \times 0.5805] = -16.7 \qquad \textbf{(22)}$$

The center vectors are then computed from equation 14 which gives

$$C_1 = j\,\frac{33{,}000}{-16.7}\Big[\,0.2(0.289 + j1.45)(0.5805 - j3.195) - (0.2 - k_2)(-2.44 - j0.926)\Big] \qquad \textbf{(23)}$$

when k_2 = 0.18 (90 per cent), $C_1 = 1{,}990\ \angle -89.9^\circ$
when k_2 = 0.20 (100 per cent), $C_1 = 1{,}890\ \angle -91.0^\circ$

From equation 18 the expression for the radius becomes

$$R_1 = \left|\frac{33{,}000 \times 1.48}{16.7}\Big[(0.2915 + j1.745)(0.2 - k_2) - 0.2(0.5805 + j3.195)\Big]\right| \qquad \textbf{(24)}$$

when k_2 = 0.18 (90 per cent), R_1 = 1,795
when k_2 = 0.20 (100 per cent), R_1 = 1,890

Locus of I_2

Under the same conditions, using equation 8 the current I_2 in transformer 2 becomes

$$I_2 = 33{,}000\,\frac{k_2(0.2915 + j1.745) - (0.2 - k_2)\,|Z_L|}{(-2.44 + j0.926) + (0.5805 + j3.195)\,|Z_L|} \qquad \textbf{(25)}$$

The same 3 points on the 2 circles for different ratios k_2 are as shown in table III.

These circles are plotted in figure 3. Connecting lines are drawn through equal values of Z_L to obtain corresponding points on circles for other values of k_2. A scale line is shown for the 90-per-cent circle. Points are indicated on the circles of I_2 for k_2 = 95, 105, and 110 per cent, but only the 110-per-cent circle is drawn in.

Table III

Z_L	I_2 (Amperes)	
	k_2 = 90 Per Cent	k_2 = 100 Per Cent
0	$4{,}025 \angle -78.7°$	$4{,}470 \angle -78.7°$
1	$2{,}310 \angle -30.2°$	$2{,}500 \angle -33.8°$
∞	$203.5 \angle 100.3°$	0

The center vectors in this case from equation 16 are:

$$C_2 = j\,\frac{33{,}000}{-16.7}\Big[k_2(0.2915 + j1.745)(0.5805 - j3.195) + (0.2 - k_2)(-2.44 - j3.195)\Big] \qquad (26)$$

when $k_2 = 0.18$ (90 per cent), $C_2 = 1{,}960 \angle -90.2°$
when $k_2 = 0.20$ (100 per cent), $C_2 = 2{,}270 \angle -89.2°$

The radii are obtained from equation 19 which gives

$$R_2 = \left|\frac{33{,}000 \times 1.77}{-16.7}\Big[(0.289 + j1.45)(0.2 - k_2) + k_2(0.5805 + j3.195)\Big]\right| \qquad (27)$$

when $k_2 = 0.18$ (90 per cent), $R_2 = 2{,}150$
when $k_2 = 0.20$ (100 per cent), $R_2 = 2{,}270$

References

1. THE PARALLEL OPERATION OF TRANSFORMERS, J. M. Weed. *Electrical World*, volume 52, November 21, 1908, page 1117.

2. PARALLEL OPERATION OF TRANSFORMERS, W. V. Lyon. *Electrical World*, volume 63, February 7, 1914, page 315.

3. PARALLEL OPERATION OF TRANSFORMERS, J. B. Gibbs. *Electric Journal*, volume 32, August 1935, page 340.

4. LOAD SHARING-DIVISION IN TRANSFORMERS HAVING UNEQUAL RATIOS AND IMPEDANCES, J. K. Catterson-Smith. *The Electrician*, volume 116, June 12, 1936, page 779.

5. PARALLEL OPERATION OF TRANSFORMERS WHOSE RATIOS OF TRANSFORMATION ARE UNEQUAL, Mabel MacFerran. AIEE TRANSACTIONS, volume 49, 1929, page 125.

6. CROSS-POTENTIAL OF A FOUR-ARM NETWORK, A. C. Seletzky, ELECTRICAL ENGINEERING, volume 52, July 1933, page 861.

7. CIRCULAR LOCI OF CURRENTS AND VOLTAGES IN A GENERAL NETWORK, A. C. Seletzky. *Journal* of the Franklin Institute, volume 222, August 1936, page 197.

Mechanical Engineering in the Electrical Industry

PROBABLY no other industry in the world offers the variety and scope for mechanical engineering that the electrical business does, according to the article "The Young Mechanical Engineer in the Electrical Industry," by A. R. Stevenson, Jr. (A'20) and E. E. Parker, which was published in *Mechanical Engineering* for October 1937, pages 725–31.

Electrical engineering is so interwoven with mechanical engineering that the electrical engineer must be familiar with mechanical matters, and, vice versa, the mechanical engineer should know considerable about electrical matters. Even in nonelectrical industries, the design of machinery includes application of electric motors and control. Because electrical engineering is recognized as a separate branch, the fact is sometimes overlooked that the design and manufacture of electrical apparatus involve to a large degree work designated as mechanical engineering. For example, after an electrical engineer has decided on the size and type of punchings and windings to give the proper magnetic-flux distribution and the insulation and electrostatic shields to give the proper distribution of electric potential, someone must do the mechanical engineering involved in designing the supporting structure, determining the heat transfer, the fluid flow of the cooling media, the lubrication, and similar factors. Furthermore, factory processes for construction of the apparatus are also purely mechanical.

Electrical apparatus is seldom used alone. It is either driven by mechanical apparatus or it drives or controls some other machinery. The electrical manufacturer, therefore, must have application engineering departments to study and sales departments to keep in touch with the mechanical industries, so that he can make proper recommendations with regard to the application of electric equipment in those industries.

The variety of mechanical engineering engaged in by an electrical company extends from the design and manufacture of kitchen mixers, clothes washers, dishwashers, and other household appliances to the design and construction of locomotives and large steam turbines. Switchgear and industrial-control apparatus, although nominally classed as electrical apparatus, depend for their success largely upon the mechanical design of the parts. For instance, in the mechanism for a 287-kv circuit breaker for Boulder Dam service, compressed springs release a force of 24,000 pounds in 0.01 second when the circuit breaker is tripped, and the mechanism develops approximately 300 horsepower for 0.06 second during interruption of a circuit. These springs are compressed by a motor and are released by an electrical impulse; otherwise, the circuit-breaker mechanism is completely a mechanical-engineering job.

Most electrical manufacturers also produce a variety of related equipment which is purely mechanical in nature, having been forced to do this to develop the electrical industry to its fullest capabilities. For instance, steam-driven electric generators were limited to about 5,000 horsepower in size because of the lack of a suitable prime mover to drive them until the electrical industry developed steam turbines that could be made in larger sizes. It is the electrical industry that has pioneered the development of the steam turbine from a few hundred to many thousand horsepower. Development work on the mercury-steam binary cycle has been carried on entirely by an electrical manufacturer in co-operation with several electrical utilities. This project includes development not only of turbines to operate with mercury vapor but also mercury boilers and condensers.

Unsymmetrical Short Circuits on Water-Wheel Generators Under Capacitive Loading

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WATER-WHEEL GENERATORS without damper windings under capacitive load may have abnormally high voltages developed across their terminals at times of unsymmetrical short circuits. These voltages are due to 2 causes. First, the difference in permeance of the magnetic circuit in the direct and quadrature axes produces, under unsymmetrical short circuits, distorted voltages which have high peak values even if there is no capacitance connected to the machine. Second, the capacitance of the line and the reactance of the machine resonate or partially resonate and produce still greater distortion of the voltages on the sound phase. The phenomenon associated with single-phase short circuits with no connected capacitive load, has been analyzed by Doherty and Nickle.[1] The present paper is concerned with the effect of the capacitive load and an analysis of the factors involved in this phenomenon. Consideration is given to the system conditions under which these harmful voltages may arise and the remedial measures which may be applied for their elimination.

The practical value of this investigation arises from the damage that might occur to system insulation or the destruction of lightning arresters that might ensue if such voltages are permitted to exist. As a matter of interest, the problem was first drawn quite forcibly to our attention by the destruction of an arrester in the field, the circumstances having been such as to present incontrovertible proof that the failure was due to the presence of excessively high sustained voltages; conditions which arresters are not expected to withstand. Relay tests were being made on an unloaded transmission line connected through a transformer to a synchronous generator without damper windings. Upon the application of a line-to-line short circuit the arrester failed. In a repeat test the arresters were removed and the line-to-ground voltages were measured and found to be of such magnitude as to account for the arrester failure. It is quite probable that other arrester failures, previously attributed to lightning or other causes, can also be explained on this basis.

The body of the paper is concerned with an oscillographic study of the factors involved in the general problem and the appendix with an analytical study of the terminal voltages which appear for a terminal-to-terminal short circuit on a generator under capacitive load.

Nature of Phenomenon

In order to form a preliminary idea of the nature of the phenomenon, a terminal-to-terminal short circuit and a capacitive load were simultaneously applied to a 100-kva 2,300-volt generator without damper windings operating at half rated voltage. Oscillograms were taken of the voltage from the shorted phases to the sound phase. As shown in the appendix from theoretical considerations, resonating points are encountered as the capacitive load is progressively decreased from a large value. If the reactance to neutral of the capacitance load at fundamental frequency is denoted by x_c and the reactances of the generator to neutral in the direct and quadrature axes are denoted by x_d' and x_q, respectively, then resonating points are reached when the quantity $x_c/\sqrt{x_d'x_q}$ is equal to n^2, where n may be any odd integer. Oscillograms are shown in figure 1 for a wide variation of $x_c/\sqrt{x_d'x_q}$. Beginning with (*a*) it will be observed that the voltage consists of a fundamental component with a pronounced third harmonic. As $x_c/\sqrt{x_d'x_q}$ increases the fundamental decreases and the third harmonic increases, until a maximum deflection, as compared with the no-load value before the short circuit, is reached in oscillogram (*e*). This oscillogram has a value of $x_c/\sqrt{x_d'x_q}$ of 8.65 which does not correspond exactly to the theoretical value of 9. However, the computed value was based upon values of x_d' and x_q for normal frequency and rated current. Actually x_d' and x_q may not be regarded as constant. In figure 2 x_d' and x_q are plotted as functions of frequency for constant current and in figure 3, as a function of current for rated frequency. The root-mean-square value of the short-circuit current of figure 1*e* varies with time but is of the order of 1.2 to 1.4 per unit.* If it is assumed that the current is 1.25 per unit and that the reactances at this current vary in the same proportion as for the smaller currents in figure 2 then the corrected value of $x_c/\sqrt{x_d'x_q}$ is 9.1. This constitutes a very close check upon the theory.

As $x_c/\sqrt{x_d'x_q}$ is further increased the third harmonic becomes smaller and the fifth harmonic larger. This is progressively illustrated until oscillograms (*j*) and (*k*) are reached. Resonance occurs between these 2 oscillograms at a value somewhat smaller than the theoretical value of 25. Continuing still further, the seventh harmonic reaches a maximum in oscillogram (*o*). The voltage resulting for a terminal-to-terminal short circuit with no connected capacity is shown in (*q*). Theoretically, of course, if the resistance is negligible the voltage for the different resonating points should be infinitely large. Actu-

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A paper recommended for publication by the AIEE committees on electrical machinery and power generation. Manuscript submitted June 10, 1937; released for publication September 16, 1937.

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The author wishes to acknowledge the assistance of H. N. Muller in calculating the curves showing the comparison between test and analytical results.

1. For all numbered references, see list at end of paper.

* In this paper the per-unit system is used in designating the machine constants.

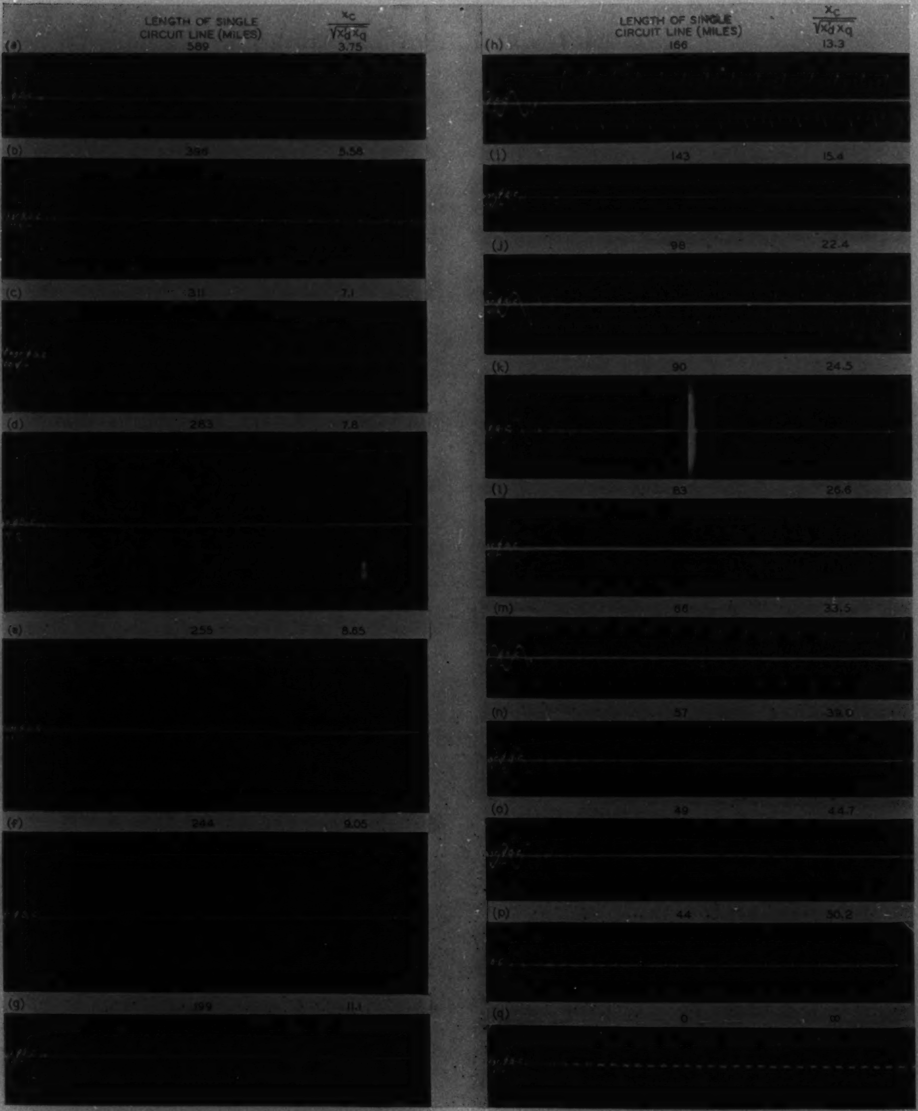

Figure 1. Effect upon the terminal voltage of varying the shunt capacitive reactance when a terminal-to-terminal short circuit is applied to a machine without damper windings

ally the resistance limits the magnitude to which the voltage rises, its effect increasing as the frequency increases. The truth of this statement is borne out by the curves of resistance for the 2 axes plotted in figure 2. These values were obtained by applying single-phase potential of variable frequency across 2 terminals of the machines with the rotor stationary as is done in the conventional method for determining x_d'' and x_q''. The resistance components of the impedances in the 2 axes are indicated as r_{ad}'' and r_{aq}''. It will be observed that for the seventh harmonic r_{aq}'' is 0.68 and r_{ad}'' is 0.17, values sufficiently high to significantly limit the voltages for resonance at this frequency. The curves of figure 2 were taken at the small currents indicated because of limitations in the power of the source. The general effect of resistances will be discussed further in the appendix.

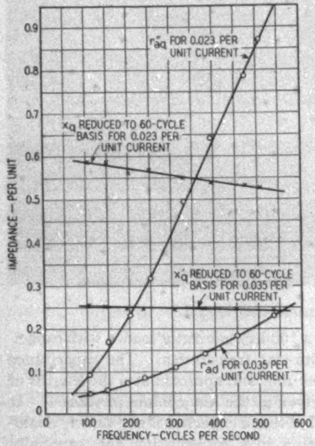

Figure 2. Variation of x_d', x_q, r_{ad}'', and r_{aq}'' with frequency

100-kva 2,300-volt machine without damper winding

It will be observed that under certain conditions an initial transient of quite high value is present. This usually occurs at even harmonic resonant values of $x_c/\sqrt{x_d'x_q}$ as evidenced by oscillograms (*a*), (*b*), and (*h*). The point of greatest significance in connection with these oscillograms is that the maximum voltages occur for resonant conditions near the third and fifth harmonics.

In order to orient one's self with regard to the length of line involved in these considerations, the figure in miles which appears above each oscillogram represents approximately the length of single circuit 66-kv or 220-kv transmission line which, with a generator having the characteristics of the one used in the test, is required to satisfy the given value of $x_c/\sqrt{x_d'x_q}$. These figures were arrived at by assuming a generator capacity of 25,000 kva, 75,000 kva, and 200,000 kva for a 66 kv, 132 kv, and 220 kv, respectively. For smaller machines the length will decrease in proportion.

Effect of Parallel Machines Having Damper Windings

In practice water-wheel generators are usually paralleled with machines having damper windings or their equivalent, that is, the generator may feed power over a line into a system which includes turbogenerators or, again, synchronous condensers may be connected to the system at the receiving end of the line. Under what conditions then may these harmful voltages appear and to what extent do parallel machines hold these voltages down? If upon the inception of a fault upon a single-circuit transmission line to which a generator without damper windings is connected, the breaker at the end remote from the generator opens first, then the condition prevails under which it is known these abnormal voltages can exist, namely, an essentially capacitive load connected to a machine without damper windings. This condition will persist until the breaker at the supply end is opened. During the interval while both breakers are closed, the machines with damper windings reduce the maximum voltages. If the line involved is a 2-circuit line, then opening the breaker at the receiving end of one line does not open the tie between the 2 ends of the system and the dangerous condition of having an open line tied to a generator cannot exist unless the second breaker at the receiving end is opened.

The extent to which connected machines with damper windings are effective is illustrated in figure 4. The schematic diagram shows the arrangement of the test equipment which represents a transmission system in miniature. Machine 1 is a generator *without* damper windings and machine 2 is a generator with *end-connected copper* damper windings. The intervening transmission line is representative of a 100-mile single-circuit line. Oscillogram (*b*) shows the phase-to-ground voltage for a phase-to-phase short circuit on the left-hand side of the line and oscillogram (*a*) the same voltage for the condition in which machine 2 is not connected to the line. The calibration of the oscillograph elements was not the same in these 2 cases, but by comparing the deflections with the no-load voltages before the short circuit it may be seen that the presence of the machine with copper dampers reduces the peak voltages to 68 per cent. In taking oscillogram (*a*) the series reactance (*j*0.47) was not in the circuit but its omission will not change the conclusions. The significant factor is that the harmonics are suppressed to a very great extent. Oscillograms (*c*) and (*d*) were taken under con-

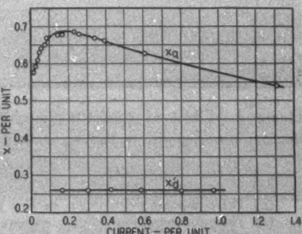

Figure 3. Variation of x_d' and x_q as a function of current

100-kva 2,300-volt machine without damper windings ditions identical to (*a*) and (*b*), respectively, except that the fault was a line-to-neutral short circuit. For shorter transmission lines or any case in which there is less reactance between the machines, the damper windings will be still more effective in limiting the excessive voltages.

Effect of Load

The question naturally arises as to the effect of connected load in suppressing the harmonics associated with these voltages. If load is taken from the generator end of a transmission line will a short circuit on an open-ended transmission line connected to the bus result in smaller voltages than if the load were absent? Oscillographic tests were made on a 100-kva generator loaded with capacitors through a delta-star transformer. The capacitance was equal to 8.85 per unit and approximates the lengths of single-circuit line given in the last column of table I. It must be borne in mind that a capacitor is not strictly analogous in characteristics to a transmission line, especially at the higher frequencies, but it is sufficiently representative for the purpose in hand. Loads of different character were then applied to the line side of the transformer.

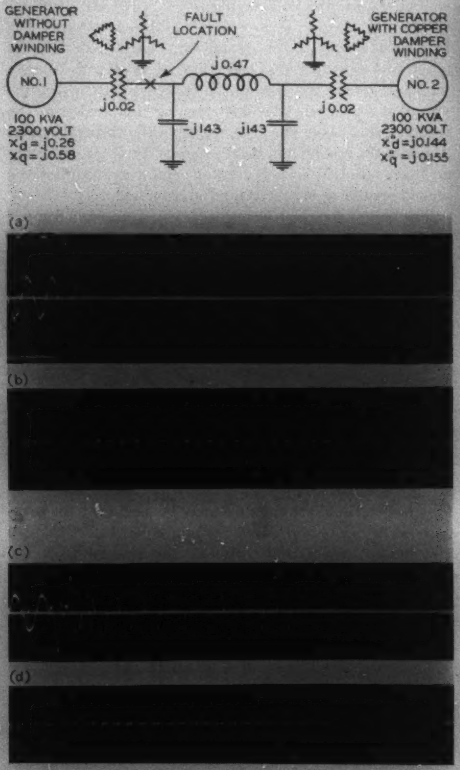

Figure 4. Effect of paralleling machine having a copper damper winding with a machine having no damper winding

Oscillograms show voltage of phase having maximum voltage

(*a*) Phase-to-phase short circuit; machine 2 not connected

(*b*) Phase-to-phase short circuit; machine 2 connected

(*c*) Phase-to-neutral short circuit; machine 2 not connected

(*d*) Phase-to-neutral short circuit; machine 2 connected

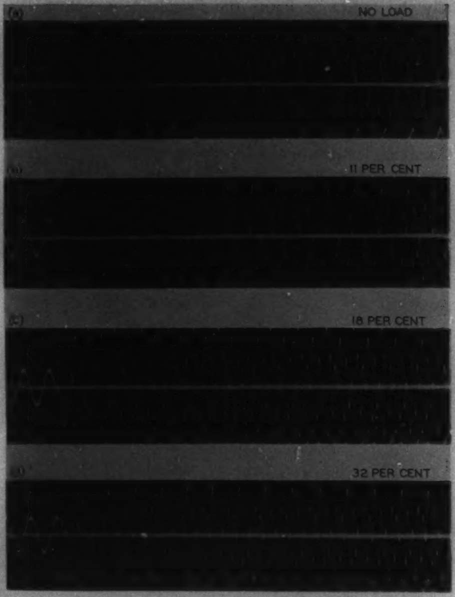

Figure 5. Effect of pure reactance load

Pure Reactance

Figure 5 shows the results of tests made with essentially pure reactance loads. To preclude the need for obtaining 3-phase reactors the load in the form of a single reactor was applied simultaneously with a phase-to-phase short circuit on the line. The capacitors were connected at the same time. The line-to-ground voltage of the unshorted phase on the load side of the transformer is shown by the oscillograms for reactor values equivalent to steady-state loads of 0, 11, 18, and 32 per cent of rated values. The reactor loading over the entire range has little if any effect upon the magnitude of these voltages or in suppressing harmonics unless very near a resonance point in which case the reactor would dissonate or detune the circuit. Thus the reactive load merely changes the resonating points. Of course, as the load reactance is still further decreased the voltage will decrease, approaching zero as the load reactance approaches zero.

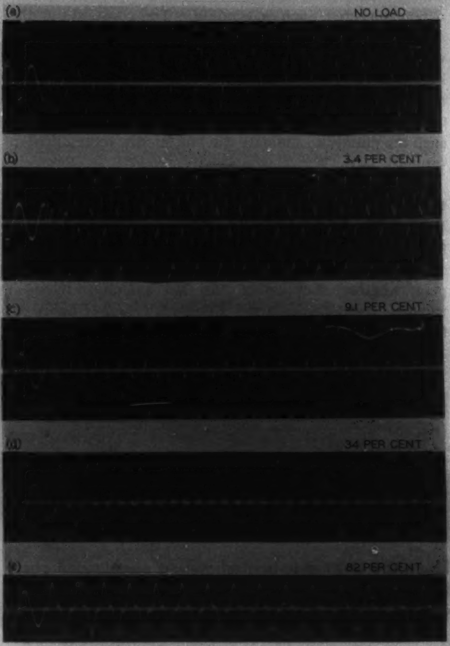

Figure 6. Effect of pure resistance load

PURE RESISTANCE

Pure resistance load, on the other hand, becomes quite effective in reducing the voltage of the sound phase as may be evidenced by the oscillograms of figure 6. A load of 34 per cent reduced the sound phase voltage to about 65 per cent of the voltage for the no-load condition.

INDUCTION MOTOR

An induction-motor load of equal kilovolt-amperes is still more effective in reducing the peak voltages than is a pure resistance load. The upper 3 curves of figure 7 show the effect upon the sound phase-to-neutral voltage on the load side of the transformer as a phase-to-phase short circuit, the capacitor load, and an induction-motor load of 0, 12.2, and 49 per cent, respectively, are simultaneously applied to the 100-kva generator. A 25-horsepower induction motor was used for this purpose, the generator being operated at half voltage and the induction motor at such voltages, by means of transformers, as to produce an impedance equivalent to the loads indicated. The induction motors were unloaded. By comparing the oscillogram voltages with the values before the short circuit, it will be seen that induction motors are quite effective in reducing these abnormal voltages. This is due to the lower impedance for the harmonics than that possessed by a proportionate pure reactance load.

The lower 3 oscillograms give verifying results for phase-to-neutral short circuits.

Damper Windings

It is shown in the appendix that for a terminal-to-terminal short circuit on an unloaded machine *without* damper windings the voltage from the sound phase to the shorted phases can be resolved into odd and even harmonics. The even harmonics, including the zero'th, decay quite rapidly (within a few cycles if several per cent resistance, representative of that in a transmission line, is inserted in the armature circuit) and the odd harmonics more slowly. The crest value of the sum of the odd harmonics just after short circuit is equal to $(^3/_2)/(x_q/x_d')$ times the crest of the normal line-to-neutral voltage. For a machine *with* damper windings this multiplying factor is $(^3/_2)(x''/x_d'')$. Thus the crest voltages, neglecting the rapidly decaying even harmonics, increase proportionately

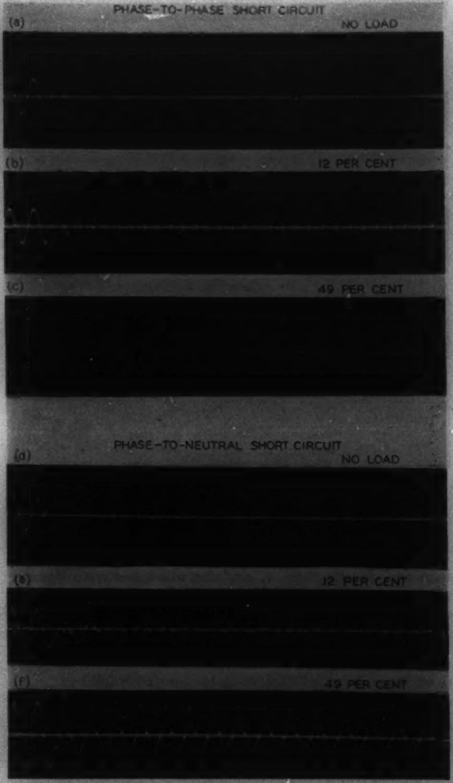

Figure 7. Effect of induction-motor load

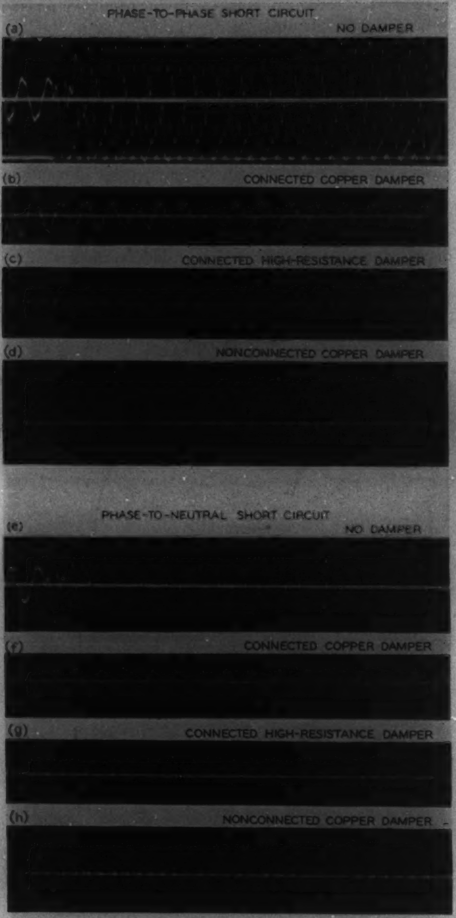

Figure 8. Effect of damper windings

to the ratio x_q/x_d' for machines without damper windings and to the ratio x_q''/x_d'' for machines with damper windings. One would expect also that the abnormal voltages encountered under capacitive loading might also vary with x_q/x_d' or x_q''/x_d''.

Tests were made on 3 100-kva synchronous generators that were identical except as to damper windings. One of the machines had no damper windings, one a copper damper, and the other an Everdur* or high-resistance damper. In addition, the tests were repeated with the machine with copper dampers after the end straps had been insulated between poles thus constituting in effect a nonconnected damper winding. The constants of the machines are given in table II. Each of the machines was in turn connected through a delta-wye bank of 3 $37\frac{1}{2}$-kva transformers to a capacitive load consisting of capacitors connected from the phase wires to the neutral point of the transformer secondary. The capacitors were of such magnitude to simulate the line lengths represented in table I.

The specific tests consisted of phase-to-phase and phase-to-neutral short circuits, the results of which are shown by the oscillograph study of figure 8. It will be observed that for both kinds of short circuits, the voltages are reduced considerably by the presence of connected dampers, whether they be of the low-resistance (copper) type or the high-resistance (Everdur) type. To this extent the surmise is borne out that the ratio x_q''/x_d'' constitutes a rough measure of the distortion one might expect. In oscillograms (*a*) and (*e*), the combination of machine reactance and line capacitance is such as to be near the resonance point for the fifth harmonic but with the decrease in machine reactance occasioned by the copper damper (the line capacitance remaining the same) the resonance point has been moved closer to the seventh as shown in oscillograms (*b*) and (*f*). For the machine with Everdur dampers [oscillograms (*c*) and (*g*)], the reactance is such as to also approach the resonating point for the seventh harmonic, but it will be observed that the amplitude of the harmonic is much smaller than that for the copper damper winding. This is because the higher values of r_{ad}'' and r_{aq}'' for Everdur (see table II) tend to prevent to a greater extent the building up of the large currents and voltages associated with resonant conditions.

Figure 9. Terminal-to-terminal voltage across sound phase for simultaneous application of terminal-to-terminal short circuit and capacitor load for a machine with nonconnected copper damper windings

Circuit near third harmonic resonance

While in this case, nonconnected dampers are not anywhere near as effective as connected dampers in reducing the peak voltages, they are somewhat more effective than no dampers. Additional terminal-to-terminal short circuits were made on machines with nonconnected damper windings under capacitive load covering a wide range of capacitance. The case for near resonance of the third harmonic is shown in figure 9. By comparison with figure 1*e* it may be seen that the voltages from the sound phase to the short-circuited phases are somewhat less. This is probably due to larger values of r_{ad}'' and r_{aq}'' for the machine with nonconnected dampers. Table II shows a variation of these constants in this general direction and at 180 cycles the difference is probably greater. In any case figures 8*d* and 8*h* show that dangerously high voltages can be attained with this kind of damper unless precautions are taken to insure that the ratio x_q''/x_d'' is made more nearly equal to unity.

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* The conductivity of Everdur is approximately 6 per cent.

Additional data[4] relative to the effect of damper windings upon the constants of machines are given in table III.

Conclusions

It has been shown that dangerously high voltages can be attained under unbalanced short circuits when synchronous generators without damper windings are connected to capacitive loads such as represented by an unloaded transmission line. These voltages may consist of very high initial transients of a few cycles duration followed by distorted waves having a slower decay. For a given machine resonating points are encountered as the length of unloaded connected line is varied. The voltages are maximum at these resonating points. The length of line required for resonance is also dependent upon the type of fault considered. A particular line represents a particular electrostatic capacity but since the fault may occur at any point, the reactance is variable. This fact increases the difficulties of attempting to operate at a point of dissonance. In general if conditions are such that resonance is obtained for a short circuit at the generator end of the line, the voltages that can be expected will be larger than if conditions are such as to produce resonance for short circuits at the far end of the line. This follows because the resistance of the line tends to prevent the building up of the currents and voltages at resonance. These abnormal voltages are larger in proportion to normal values on the line side of transformers than on the machine side.

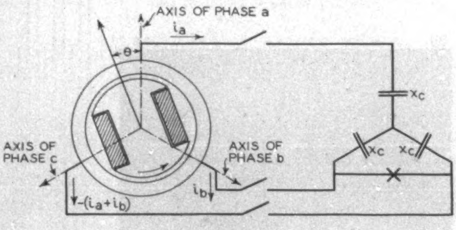


Figure 10

If other synchronous machines having damper windings or their equivalent are kept in parallel or if sufficient resistance or induction-motor load is maintained connected to the machines, the excess voltages may be reduced a very considerable degree.

It has been shown that these phenomena are very closely associated with the ratio x_q/x_d' in the case of machines without damper windings and x_q''/x_d'' in the case of machines with damper windings, the magnitude of the abnormal voltages increasing as this ratio increases from unity. Connected damper windings, either high or low resistance, because their presence results in a machine for which this ratio is very nearly equal to unity, are very effective in preventing these abnormally high voltages. Damper windings which result in a higher value of this ratio, such as may be the case for windings not connected between poles, are not so effective in preventing these voltages.

Tests have shown (figure 1*e*) that the crest value of the voltage from the sound phase to the shorted phases may attain a value 5.5 times the normal crest line-to-line value. Without making an attempt to obtain resonant conditions, the line-to-neutral voltages for a line-to-line short circuit (figure 8*a* and 8*d*) gave a measured value of 2.9 times normal crest value for both a machine with connected and one with nonconnected copper damper windings.

Appendix

In approaching the analytical investigation of this problem the simplest case will be chosen which still incorporates the essential

Table I. Lengths of Single-Circuit Transmission Lines Having Capacitance Impedance of 8.85 Per Unit

Line Voltage (Kilovolts)	Conductor	Spacing (Feet)	Rating of Generator (Kilovolt-amperes)	Length of Line (Miles)
22	00 A.C.S.R.	4	10,000	372
66	000 Copper	6	25,000	110
132	0000 Copper	13	75,000	92
220	605,000 circular mil A.C.S.R.	21	200,000	87

Table II. Constants of a Synchronous Generator as Affected by Type of Damper Winding

100 Kva, 2,300 Volts, 25.2 Amperes

Type	x_d'	x_q	$\sqrt{x_d' x_q}$	$\frac{x_q}{x_d'}$	r_{ad}''	r_{aq}''
No damper	0.260	0.577	0.388	2.22	0.028	0.105
	x_d''	x_q''	$\sqrt{x_d'' x_q''}$	$\frac{x_q''}{x_d''}$		
Connected copper	0.157	0.146	0.151	0.93	0.036	0.047
Connected Everdur	0.171	0.157	0.164	0.92	0.063	0.111
Nonconnected copper	0.154	0.390	0.245	2.53	0.037	0.113

Table III. Constants of a Synchronous Condenser as Affected by Type of Damper Winding

5,000 Kva, 4,000 Volts, 721 Amperes

Type	r_2		$x_2=\frac{1}{2}(x_d''+x_q'')$	
	Test	Calculated	Test	Calculated
No damper	0.045	0.040	0.75	0.69
Connected copper	0.026	0.029	0.195	0.215
Connected brass	0.045	0.044	0.195	0.215
Connected Everdur	0.12	0.125	0.20	0.215

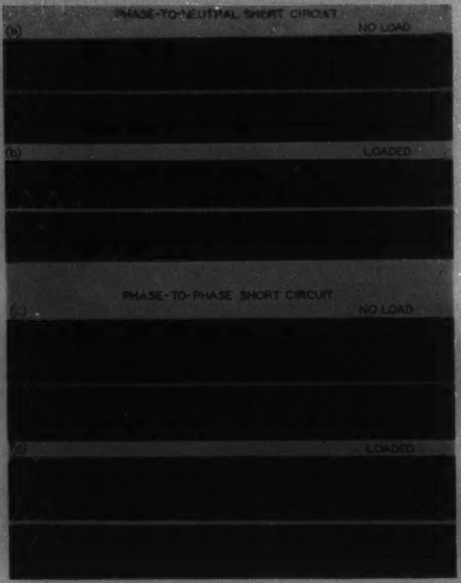


Figure 11. Effect of loading machine with capacitive load before short circuit

factors of the problem. To this end consideration will be given to the voltage between the short-circuited and the sound terminals of a synchronous machine without damper windings as a terminal-to-terminal short circuit and a 3-phase capacitive load are applied simultaneously. The schematic diagram of the circuit is shown in figure 10. The notation and assumptions will be the same as that used by Park[2,3] in his papers relating to the theory of synchronous machines. Thus the machine will be "idealized" to the extent that each armature winding will be assumed to produce a sinusoidal wave of magnetomotive force. Saturation, hysteresis, and eddy currents will be neglected.

The "per unit" system will be employed in which the units are defined as follows:

Armature current	$\sqrt{2}$ rated value
Armature voltage	$\sqrt{2}$ rated terminal-to-neutral value
Armature flux	value which will generate rated voltage at no load
Field current	value which will produce unit armature flux at no load
Reactance	ratio of normal phase-to-neutral voltage to normal phase current
Angle	electrical radian
Time	time for rotor moving at rated speed to move through one electrical radian

Let

i_a, i_b, i_c = terminal currents
e_a, e_b, e_c = terminal-to-neutral voltages
ψ_a, ψ_b, ψ_c = terminal-to-neutral linkages
I_d = field current
θ = angular displacement of rotor from axis of phase a

From figure 10, it is evident that

$$I_c = -(i_a + i_b) \tag{1}$$

so that equation 3 of reference 3 becomes

$$i_d = \frac{2}{3}\left\{\left[\cos\theta - \cos\left(\theta + \frac{2\pi}{3}\right)\right]i_a + \left[\cos\left(\theta - \frac{2\pi}{3}\right) - \cos\left(\theta + \frac{2\pi}{3}\right)\right]i_b\right\} \tag{2}$$

The flux linkages with the field winding, Ψ, are given by

$$\Psi = I_d - (x_d - x_d')i_d \tag{3}$$

Therefore, corresponding to any sudden change in armature currents,

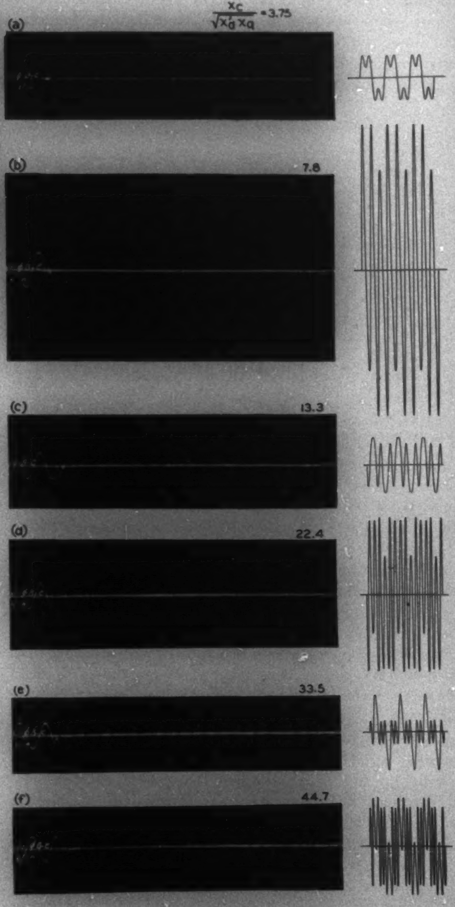


Figure 12. Comparison between test and calculated values of voltage

there follows from this equation (since Ψ cannot change instantly) that

$$0 = \Delta I_d - (x_d - x_d')i_d \tag{4}$$

where ΔI_d is the current induced in the field winding. Therefore, upon substituting 2 in 4

$$\begin{aligned}\Delta I_d = \frac{2(x_d - x_d')}{3} \Bigg\{ & \left[\cos\theta - \cos\left(\theta + \frac{2\pi}{3}\right)\right] i_a + \\ & \left[\cos\left(\theta - \frac{2\pi}{3}\right) - \cos\left(\theta + \frac{2\pi}{3}\right)\right]\Bigg\}\end{aligned} \tag{5}$$

Equations 1 to 3 of Park's paper give the flux linkages ψ_a, ψ_b, and ψ_c for any values of i_a, i_b, i_c, and I_d. If the value of i_c from 1 and ΔI_d from 5 are substituted in these equations, the values of flux linkages for the suddenly appearing armature currents are obtained. These are:

$$\begin{aligned}\psi_a = -\frac{x_d' - x_q}{3} \Bigg\{ & \left[\cos 2\theta - \cos\left(2\theta + \frac{2\pi}{3}\right)\right] i_a + \\ & \left[\cos\left(2\theta - \frac{2\pi}{3}\right) - \cos\left(2\theta + \frac{2\pi}{3}\right)\right] i_b \Bigg\} - \frac{x_d' + x_q}{2} i_a\end{aligned} \tag{6}$$

$$\begin{aligned}\psi_b = -\frac{x_d' - x_q}{3} \Bigg\{ & \left[\cos\left(2\theta - \frac{2\pi}{3}\right) - \cos 2\theta\right] i_a + \\ & \left[\cos\left(2\theta + \frac{2\pi}{3}\right) - \cos 2\theta\right] i_b \Bigg\} - \frac{x_d' + x_q}{2} i_b\end{aligned} \tag{7}$$

$$\begin{aligned}\psi_c = -\frac{x_d' - x_q}{3} \Bigg\{ & \left[\cos\left(2\theta + \frac{2\pi}{3}\right) - \cos\left(2\theta - \frac{2\pi}{3}\right)\right] i_a + \\ & \left[\cos 2\theta - \cos\left(2\theta - \frac{2\pi}{3}\right)\right] i_b \Bigg\} + \frac{x_d' + x_q}{2} (i_a + i_b)\end{aligned} \tag{8}$$

In addition to the flux linkages due to the suddenly appearing armature currents there also exist flux linkages due to the normal value of field current. These values are

$$\psi_a = I_d \cos\theta \tag{9}$$

$$\psi_b = I_d \cos\left(\theta - \frac{2\pi}{3}\right) \tag{10}$$

$$\psi_c = I_d \cos\left(\theta + \frac{2\pi}{3}\right) \tag{11}$$

The total flux linkages between b and c for the sudden change in armature current (including the normal field current) are

$$\begin{aligned}\psi_b - \psi_c = {} & \sqrt{3}\, I_d \sin\theta - (x_d' - x_q) \times \\ & \left[i_a \cos\left(2\theta - \frac{2\pi}{3}\right) - i_b \cos 2\theta\right] - \frac{x_d' + x_q}{2}(i_a + 2i_b)\end{aligned} \tag{12}$$

and for the flux linkages across a and b

$$\begin{aligned}\psi_a - \psi_b = {} & \sqrt{3}\, I_d \sin\left(\theta + \frac{2\pi}{3}\right) - (x_d' - x_q) \times \\ & \left[i_a \cos 2\theta - i_b \cos\left(2\theta + \frac{2\pi}{3}\right)\right] - \frac{x_d' + x_q}{2}(i_a - i_b)\end{aligned} \tag{13}$$

The voltage across the terminals b and c is equal to

$$\frac{d}{dt}(\psi_b - \psi_c) = 0$$

or

$$\psi_b - \psi_c = \text{constant} \tag{14}$$

The significance of this equation is that the flux linkages immediately before and immediately after short circuit are equal, an application of Doherty's theorem of "constant flux linkages." Stated otherwise, the constant is determined from the value just before short circuit. If

$$\theta = t + \alpha \tag{15}$$

in which t is measured from the instant of short circuit, then

$$\begin{aligned}\sqrt{3}\, I_d \sin\alpha = {} & \sqrt{3}\, I_d \sin\theta - \\ & (x_d' - x_q)\left[i_a \cos\left(2\theta - \frac{2\pi}{3}\right) - i_b \cos 2\theta\right] - \\ & \frac{x_d' + x_q}{2}(i_a + 2\, i_b)\end{aligned} \tag{16}$$

or

$$i_b = \frac{\sqrt{3}\, I_d [\sin\alpha - \sin\theta] + \left[(x_d' - x_q)\cos\left(2\theta - \frac{2\pi}{3}\right) + \frac{x_d' + x_q}{2}\right] i_a}{(x_d' - x_q)\cos 2\theta - (x_d' + x_q)} \tag{17}$$

The voltage across terminals a and b is equal to the voltage across the capacitors and also the time differential of the flux linkages across a and b so that

$$e_a - e_b = \frac{d}{dt}(\psi_a - \psi_b) = \frac{3}{2} x_c \int_0^t i_a dt$$

Upon substituting 13 and 17 into this equation,

$$\begin{aligned}\frac{d}{dt}\Bigg\{ & \sqrt{3}\, I_d \sin\left(\theta + \frac{2\pi}{3}\right) - \left[(x_d' - x_q)\cos 2\theta + \frac{x_d' + x_q}{2}\right] i_a + \\ & \frac{(x_d' - x_q)\cos\left(2\theta + \frac{2\pi}{3}\right) + \frac{x_d' + x_q}{2}}{(x_d' - x_q)\cos 2\theta - (x_d' + x_q)} \sqrt{3}\, I_d [\sin\alpha - \sin\theta] + \\ & \frac{(x_d' - x_q)\cos\left(2\theta + \frac{2\pi}{3}\right) + \frac{x_d' + x_q}{2}}{(x_d' - x_q)\cos 2\theta - (x_d' + x_q)} \times \\ & \left[(x_d' - x_q)\cos\left(2\theta - \frac{2\pi}{3}\right) + \frac{x_d' + x_q}{2}\right] i_a \Bigg\} = \\ & \frac{3}{2} x_c \int_0^t i_a dt\end{aligned}$$

or rearranging

$$\begin{aligned}& \sqrt{3}\, I_d \frac{d}{dt} \times \\ & \left\{ \frac{\cos\left(2\theta + \frac{2\pi}{3}\right) - \frac{x_q + x_d'}{2(x_q - x_d')}}{\cos 2\theta - \frac{x_q + x_d'}{2(x_q - x_d')}} [\sin\alpha - \sin\theta] + \sin\left(\theta + \frac{2\pi}{3}\right) \right\} = \\ & + (x_q - x_d') \frac{d}{dt} \left[\left\{ -\left[\cos 2\theta - \frac{x_q + x_d'}{2(x_q - x_d')}\right] + \right.\right. \\ & \qquad \frac{\cos\left(2\theta + \frac{2\pi}{3}\right) - \frac{x_q + x_d'}{2(x_q - x_d')}}{\cos 2\theta + \frac{x_q + x_d'}{x_q - x_d'}} \times \\ & \left.\left. \left[\cos\left(2\theta - \frac{2\pi}{3}\right) - \frac{x_q + x_d'}{2(x_q - x_d')}\right] \right\} i_a \right] + \frac{3}{2} x_c \int_0^t i_a dt\end{aligned} \tag{18}$$

By further manipulation, whose proof space will not permit, it may be shown that this equation can be written in the following form

$$\frac{3}{2} I_d \frac{d}{dt} f(t) = \frac{3}{2}\sqrt{x_q x_d'} \frac{d}{dt}[F(t)\, i_a] + \frac{3}{2} x_c \int_0^t i_a dt \tag{19}$$

in which

$$f(t) = K' [\epsilon^{j\theta} + b\epsilon^{j3\theta} + b^2\epsilon^{j5\theta} + \ldots . + \epsilon^{-j\theta} + b\epsilon^{-j3\theta} + b^2\epsilon^{-j5\theta} + \ldots .]$$

$$- \sin\alpha \left[\frac{1}{\sqrt{3}} + jb\epsilon^{j2\theta} + jb^2\epsilon^{j4\theta} + jb^3\epsilon^{j6\theta} + \ldots . - jb\epsilon^{-j2\theta} - jb^2\epsilon^{-j4\theta} - jb^3\epsilon^{-j6\theta} + \ldots .\right] \quad (20)$$

$$F(t) = [1 + b\,\epsilon^{j2\theta} + b^2\epsilon^{j4\theta} + b^3\epsilon^{j6\theta} + \ldots . + b\epsilon^{-j2\theta} + b^2\epsilon^{-j4\theta} + b^3\epsilon^{-j6\theta} + \ldots .] \quad (21)$$

and

$$b = -\frac{\sqrt{x_q} - \sqrt{x_d'}}{\sqrt{x_q} + \sqrt{x_d'}} \quad (22)$$

$$K' = \frac{\sqrt{x_q}}{\sqrt{x_q} + \sqrt{x_d'}} \quad (23)$$

The solution sought, namely, the voltage from terminal *a* to *b*, is equal to last term of equation 19. The terms in 19 were arranged in that particular order because it suggests an equivalent problem to which it may be reduced, namely a constant capacitor $(3/2)x_c$ and a variable reactor having a mean value $(3/2)\sqrt{x_d'x_q}$ connected in series. The reactor varies harmonically in accordance with equation 21. The problem then consists of determining the voltage drop across this constant capacitor as the voltage given by

$$\frac{3}{2} I_a \frac{d}{dt} f(t)$$

is suddenly applied across the combination. This equivalent circuit suggests that resonance points exist for values of $x_c/\sqrt{x_q x_d'}$ equal to the square of the integers. The applied voltage equals the voltage across the sound phase for a terminal-to-terminal short circuit with no connected capacitors.

The formulation of the problem which resulted in equation 19, neglected the resistances in all circuits. The effect of resistance is dependent upon the particular component of the solution affected. Thus the odd harmonics of the applied voltage decrease gradually to their sustained value along an exponential curve whose time constant, which as shown by Doherty and Nickle,[1] is

$$T_d' = \frac{1}{\sigma_f} = \frac{x_d' + \sqrt{x_d'x_q}}{x_d + \sqrt{x_d'x_q}} T_{d0} \quad (24)$$

The even harmonics of the applied voltage decrease to zero, and their time constant as shown also by Doherty and Nickle[1] is

$$T_a = \frac{1}{\sigma_a} = \frac{\sqrt{x_d'x_q}}{r} \text{ in seconds}$$

$$= \frac{\sqrt{x_d'x_q}}{r} 2\pi f \text{ in radians} \quad (25)$$

The time constant of a circuit consisting of a reactor x_L, capacitor x_c, and resistance r (all in per unit) is

$$T = \frac{x_L}{2r} \text{ in seconds}$$

$$= \frac{x_L}{r} \pi f \text{ in radians} \quad (26)$$

Thus steady-state conditions in such circuit would be attained in a time equal to approximately $3T$.

For the general solution, therefore, one would expect the voltage across the capacitor obtained by the solution of 19 to exist for possibly a cycle, since the effect of resistance might not have had time to become effective in this time. This should be followed by a rather rapid change because of the disappearance of the even harmonics of 20 in accordance with T_a of 25 and also the approach to the steady state solution for the odd harmonics of 20 in accordance with 26. This change should be followed by a more gradual decay in accordance with 24. The general performance outlined above is borne out by the oscillograms shown in the body of the paper, which in general show an initial transient that persists for just a few cycles, followed by a transient that lasts about a second. If the short circuit occurs out on the transmission line, the time constants T_a and T of equations 25 and 26 are reduced further, so that the initial transients decay still more rapidly than for faults on the terminals of the machine. The nature of the initial transient depends upon the instant during the cycle at which short circuit occurs. If α of 20 is equal to zero only odd harmonic voltages are applied to the circuit. In general, the excessively high voltages occur near resonance points for odd harmonics. For these values of $x_c/\sqrt{x_d'x_q}$ the initial transient delays the appearance of the crest value of voltage for about a cycle as evidenced by figures 1*e*, *f*, *k*, and *l*. For other values of $x_c/\sqrt{x_d'x_q}$, the initial transient requently results in much higher peaks during the first cycle than occurs subsequently. Illustrations of initially high peaks are offered by figures 1*a*, *b*, *c*, and *h*. For the high frequencies associated with large values of $x_c/\sqrt{x_d'x_q}$ the effective resistance becomes so high as to damp out rapidly the transients due to the high-frequency components. The character of the voltage, therefore, approaches that of the record obtained when no capacitors are connected to the machine. Compare oscillograms, figures 1*p* and *q*.

The principal virtue of a comparison of calculated and test curves of terminal voltage in a problem of this nature is the verification that no important factor has been omitted in the analysis. The rigorous solution even for the initial condition represented by equation 19 is quite involved and, after all, the initial boundary conditions set up by this case are not truly representative of the conditions met in practice. First, in practice, the machine will be under capacitive loading at the time of short circuit. However, this particular point makes little difference as evidenced by the oscillograms of figure 11 which show the effect upon the initial transients as influenced by the initial loading condition for similar short circuits. Second, of greater importance is the fact that the practical boundary condition most likely to be met is the opening of a breaker at the receiving end of a faulted line after the short circuit had been on for some time and the flux conditions within the machine had had ample time to change materially from the no-load conditions upon which the present development is premised. In view of these considerations the labor and difficulties incident to a determination of the initial transient voltages are not justified. However, the much simpler case of the quasi-steady-state solution for equation 19 in which the even harmonics of applied voltage have disappeared and the rapid transients due to the circuit constants have also disappeared, is justified. To be specific, the assumption will be made that T_a of equation 25 and T of equation 26 are zero and that T_d' is infinitely large. The transients associated with the field winding have not had opportunity to change appreciably. This solution will now be obtained.

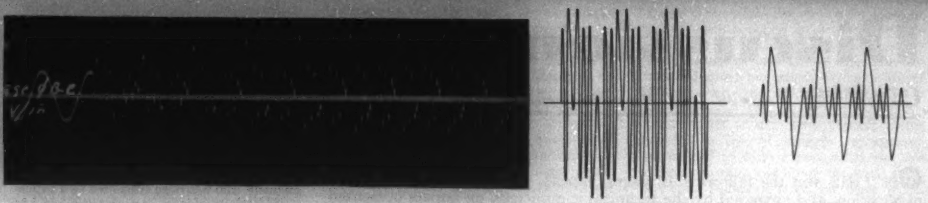
The solution will follow the line of successive approximations. It will be assumed that a voltage e_n equal to the odd terms of the applied voltage of 19 is applied to a reactor of constant value, $(3/2)\sqrt{x_q x_d'} = x_L$, and a capacitor of impedance $(3/2)x_c$ connected in series. For this simple circuit the current i_n' for each harmonic component can be obtained. Thus

$$e_n = j\frac{3}{2}K' [\epsilon^{j\theta} + 3b\epsilon^{j3\theta} + 5b^2\epsilon^{j5\theta} + \ldots . \quad \epsilon^{-j\theta} + 3b\epsilon^{-j3\theta} + 5b^2\epsilon^{-j5\theta} + \ldots .] \quad (27)$$

and

$$x_L i_n' = \frac{1}{j}\sum_1^n Y_n E_n \epsilon^{jnt} = \frac{1}{j}\sum_1^n \frac{n}{\left(n^2 - \frac{3x_c}{2x_L}\right)} E_n \epsilon^{jnt} \quad (28)$$

where n is odd integers.



(a) (b) (c)

Figure 13. Comparison between test and calculated values of voltage

$x_c/\sqrt{x_d'x_q} = 44.7$ (*a*) Test (*b*) Neglecting resistance (*c*) Including resistance

Actually the reactor, x_L, is not constant but varies harmonically with time. The instantaneous flux linkages, assuming that the current i_n' flows, is obtained by multiplying 28 by 21 giving the quantity $x_L i_n' F(t)$. The drop, e_L', across the reactor for this current is then

$$e_L' = \frac{d}{dt}\left[x_L i_n' F(t)\right] \tag{29}$$

and the drop across the condenser for the current i_n' is

$$e_c' = -j\,\frac{3}{2}\,\frac{x_c}{x_L}\,\frac{(x_L i_n')}{n} \tag{30}$$

The sum of e_L' and e_c' gives the voltage necessary to force the current i_n' through the capacitor and variable reactor. This sum will not equal the actual applied voltage but the excess or deficiency will be a second order quantity. Thus let

$$e - e_L' - e_c' = e' \tag{31}$$

Now let the voltage e' be absorbed in the constant x_L and $(3/2)x_c$ circuit and obtain a second current i'' through the application of 28. Assume the currents i' and i'' flow and obtain the instantaneous flux linkages by multiplying $(x_L i' + x_L i'')$ by 21. The time differential of this quantity gives the drop, e_L'', across the reactor for the assumed current flow and the drop, e_c'', across the condenser is

$$e_c'' = \frac{3}{2}\,\frac{x_c}{x_L}\,\frac{(x_L i' + x_L i'')}{n} \tag{32}$$

As before, determine the excess or deficiency between the applied voltage e and the sum of the drops e_L'' and e_c''. Thus

$$- e_L'' - e_c'' = e'' \tag{33}$$

Operate upon e'' as upon e'. By successive applications of these steps e^n will become negligibly small. The desired solution is the last value of e_c obtained.

This method has been applied to a number of cases, the results of which are shown in figure 12 which offers a comparison between test and calculated results. Since the calculations do not include the initial transients a rough comparison, neglecting the field transients which merely reduces the magnitude but does not affect the wave shape, may be made between the last few cycles of the oscillograms and the calculated curves. It will be observed that the results are quite close for those cases which are not near odd harmonic resonance, namely (*a*), (*c*) and (*e*). The lack of agreement of the other cases is due primarily to the assumption that resistance is neglected. Near resonance the resistance assumes great importance in limiting the current and also the voltage. Aside from affecting the magnitude of the voltage the resistance also introduces dissymmetry in the wave shape. To a lesser degree than the effect of resistance, the variation of reactance with frequency also contributes to the discrepancy between test and calculated results.

In order to verify the effect of resistance, case figure 12*e* was recalculated taking resistance into consideration by introducing a series resistance into the circuit equal to 0.05 *n* per phase or 0.075 *n* in the equivalent circuit. In the absence of more definite knowledge of the resistance at the higher currents and frequencies, this value of resistance cannot be regarded as more than an intelligent guess. The results of this calculation are plotted in figure 13. It will be observed that the wave shape of the calculated result including resistance, partakes of the general character of the oscillogram. The similarity is about as close as can be expected in view of the somewhat arbitrary assumption regarding the resistance. The seventh harmonic in particular is suppressed considerably as compared to the calculation in which resistance was neglected. In many of the calculations, and particularly this one, the solution converged very slowly which necessitated a large number of steps in the method of successive approximation.

References

1. Synchronous Machines IV, Doherty and Nickle. AIEE Transactions, volume 47, April 1928, page 457.

2. Definition of an Ideal Synchronous Machine and Formula for the Armature Flux Linkages, R. H. Park. *General Electric Review*, June 1928, pages 332–4.

3. Two Reaction Theory of Synchronous Machines, R. H. Park. AIEE Transactions, volume 48, July 1929, page 716.

4. Damper Windings for Water Wheel Generators, C. F. Wagner. AIEE Transactions, volume 50, March 1931, pages 140–51.

General Electric Photo

Stator frame of a 13,000-volt 35,000-kva single-phase 25-cycle water-wheel generator, designed to operate at 100 rpm

Discussions

Of AIEE Papers—as Recommended for Publication by Technical Committees

ON THIS and the following 12 pages appear discussions submitted for publication, and approved by the technical committees, on papers presented at the sessions on instruments and measurements, education, and insulation co-ordination at the 1937 AIEE summer convention, Milwaukee, Wis., June 21–25. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers. Other discussion of summer convention papers will be published as it is made available.

Members anywhere are encouraged to submit written discussion of any paper published in ELECTRICAL ENGINEERING, which discussion will be reviewed by the proper committee and considered for possible publication in a subsequent issue. Discussions of papers scheduled for presentation at any AIEE meeting or convention will be closed 2 weeks after presentation. Discussions should be (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to AIEE headquarters, 33 West 39th Street, New York, N. Y.

A Suggested Course on Industrial Economics and Business Methods

Discussion and author's closure of a paper by R. E. Hellmund published in the April 1937 issue, pages 446–54, and presented for oral discussion at the education session of the summer convention, Milwaukee, Wis., June 22, 1937.

A. H. Lovell (University of Michigan, Ann Arbor): I believe the author is offering a distinct contribution to engineering economy and has outlined a very successful course of advanced grade for engineers actually in contact with manufacturing. It would appear difficult, however, to accomplish such training in an undergraduate college course because of the lack of design and manufacturing experience in the students together with their diversity of professional interest. Furthermore, there is a dearth of public costs and practical problem material available to an instructor who is not an integral member of a manufacturing organization. The University of Michigan has tried to present the fundamentals of engineering economy to its electrical students for the past 15 years using the senior course in power plants and distribution as the vehicle. This work follows 6 semester-hours of classical fundamental economics taught by our economics department. I wish to emphasize that, at present, for the college undergraduate, the field of generating stations is far richer in public engineering problem material and typical costs than is that proposed by the manufacturing industry.

M. G. Malti (Cornell University, Ithaca, N. Y.): I have nothing but praise for Mr. Hellmund's scholarly paper and I consider the bibliography as particularly valuable to those interested in this subject. I do however want to make a few remarks which are applicable to this as well as to all papers which recommend the inclusion of certain courses in engineering curricula.

A visitor found his host engaged in constructing a cabinet. Upon enquiring whether his host had had a course in wood work, the guest was told that the would-be carpenter had had no course in wood work but was constructing the cabinet out of plans he had acquired.

Many of us know the famous *psychologist* Doctor Thurston of Chicago. But few of us know that Doctor Thurston graduated as a *mechanical engineer* from Cornell University.

Kettering has stated that he generally tries to give a graduate a job in which he has had no previous training because the man's mind is not prejudiced by what he had learned in college.

This and similar papers, dealing with particular topics which engineering colleges should or should not teach, opens the broad question of what is the purpose of an engineering education—nay all education. To my mind the purpose of education is to develop one's ability to:

a. Study independently of teachers.
b. Synthesize isolated facts.
c. Generalize from fundamentals.
d. View facts objectively.
e. Visualize things.
f. Do original work.

Notice that nothing has been said about knowledge of facts of engineering or economics or psychology or any other branch of science. The reason is that facts are quickly forgotten. *We use facts merely as vehicles to train the mind.* Very few engineers remember how to integrate sine x. But the training they acquired in analysis and straight thinking from their course in mathematics remains with them to the end of their days.

These remarks should not be interpreted to mean that I am opposed to training along the lines suggested in this paper. Indeed I recognize the value of economics not only to engineers but also to all professional and business men. For this very reason I am also in favor of training in "human relations." I do maintain, however, that any engineer who has been subjected to a proper and well-balanced mental training can and should be able to read and assimilate the contents of Mr. Hellmund's bibliography merely through his own efforts and without the advantage (or perhaps the disadvantage) of a college course.

I would like to add another word regarding the economic aspects of this course. The value of such a course depends largely on the caliber of the person teaching it. If it is taught by one of our academic economists it is likely to consist either of antiquated economic theories or of mere statements of economic facts with very little emphasis placed on correlation, analysis, synthesis, and other mental processes which the student can use in solving his future economic problems. This remark is based on the reaction of our engineering students to courses now offered to engineers in economics. The teacher of such a course should be an experienced mature individual who knows the facts, who knows these facts as a part of a science, and who possesses the ability to put his science across. Persons with these qualifications in "*industrial economics*" are rare and command salaries far beyond the scale of university salaries.

In view of these facts I believe that the plan, adopted by Mr. Hellmund, of teaching this course as a part of the training that a company gives to its cadet engineers, seems to be the best solution to the problem.

R. C. Putnam (Case School of Applied Science, Cleveland, Ohio): Mr. Hellmund's paper gives pertinent and challenging suggestions to the teachers of electrical engineering. In this regard, I believe that it will be of interest to bring before this discussion an independent, parallel development that has been a part of the electrical engineering curriculum at Case for the past 3 years.

Briefly, this is twofold: first, a course in engineering economy given to all seniors in electrical engineering, and second, an integrated group of studies on business and engineering administration subjects which may be optioned by the senior student.

Since this second part will be discussed next week at the convention of the Society for the Promotion of Engineering Education I shall not take it up here.

The course in engineering economy is similar in aims and content to the suggested course outlined by Mr. Hellmund in this paper. The treatment, however, is somewhat different. A 3-hour course for one semester, it comes in the last of the senior year, in order to give the student all the technical background and maturity of outlook possible.

It first considers the fundamentals of engineering economy, such as the various factors involved in problems of immediate economy as contrasted to the ultimate economy where long-range considerations are necessary, break-even points of equal economy, the economics of capacity, of replacement, and of future increased demand. This includes the study of depreciation and its various methods of computation, of sinking funds, amortization, capitalized cost, and the various other methods of comparing present out of pocket expenses of maintenance, labor, etc., with the more intangible costs of capital expenditure, either present or future.

The second part of the course is devoted to consideration and solution of problems in the generation, distribution, and application of power and in the design, manufacture, and sales of electrical apparatus. Here the problems are based on case material furnished by electrical manufacturers, public utilities, etc. Some involve an understanding of public utility rates and their underlying costs.

This may sound like a lot of material to be covered in one course, but it must be kept in mind that the object is to give the student an understanding and appreciation of the economic principles which an electrical engineer should know for the proper practice of his profession. After the fundamentals have been established, a comparatively few well chosen problems should give such a background.

As previously mentioned, this course has now been given for 3 years, and the reaction of students, alumni, and those in industry who are acquainted with the work has been most gratifying.

E. D. Ayres (University of Wisconsin, Madison): I have been requested to discuss Mr. Hellmund's paper in the light of the studies which I have been making concerning the teaching of business and economics to engineers. Frankly, it is a great pleasure to get this opportunity, because I believe Mr. Hellmund has brought you not just another paper, but a note which I am convinced must be sounded loud and long until the engineering educator realizes its importance.

Coming out of industry into teaching 7 years ago I was convinced then that there was something fundamentally amiss with an education which divorced engineering from its normal economic atmosphere. After 5 years of building up a comprehensive course at Wisconsin comparable to Mr. Hellmund's suggested course, and after 2 years of intensive study, analysis, and report on the subject of what should be done about teaching business and economics to engineers, I find myself with a message which I believe to be exceptionally sound and carefully considered in the light of criticism and experience.

We hear on both sides of the fence—that is both in college and in industry—that the job of the engineering college is to teach fundamentals. Nevertheless the college has for one reason or another steadily refused to accept this duty with respect to the economic considerations of engineering. As any engineer in industry will agree, the time of most engineers is taken up to a great extent with economic considerations. (See Mr. Hellmund's paper, second column, line 8, page 446, ELECTRICAL ENGINEERING, April 1937.) Why then are not these considerations just as important as other fundamental studies in engineering? The answer is decidedly that they are. But our teaching system is frankly not equipped (for a discussion of the implications of this sentence see "Treatment of Cost Aspects of Engineering in School," by Edmund D. Ayres, page 477, *Journal of Engineering Education*, February 1936) to furnish the background nor "pocket-book consciousness" so essential to efficient handling of these matters. The issue is therefore one of leaving this matter with industry where it has largely been or doing something about it in college.

It is not uncommon—but it is inconsistent for the "dyed in the wool fundamentalist" in engineering to cling tenaciously to the sound idea of "teaching fundamentals" and to cast into "outer darkness" all suggestions toward improvement in the treatment of the cost aspect of engineering yet deplore in the same breath the "hired man" status of the professional engineer. Gentlemen, there is but one solution to the dilemma, and it is in training the engineer early and often for leadership upon the firm base of an understanding of the economic and social factors which govern the world in which he must move. From the viewpoint of this broader problem the college must assume a responsibility.

The special course in adminstrative engineering, industrial engineering, and the like cannot solve the problem either. They are excellent treatments for the "commercially minded" student, but they do not reach the "backbone of our profession"—the technical engineer. These courses must weaken the engineering preparation of the student to accomplish their goal and I have ample proof that they do. To reach the technical engineer we must do a better job in his particular college curriculum or rely upon a post scholastic effort for both the treatment of the economic aspects of engineering and the generation of an ability for the engineer to express himself orally and on paper.

To put strength into any move to accomplish these ends, the start must in general be made in college. Living with this problem will force you just as it has me to state that the engineering college must accept the duty of including the fundamentals of economic considerations in the college engineering curriculum. Long study of the problem will also bring you, I believe, to the conclusion that the comprehensive survey course is the only practical solution in sight for the technical engineer. I should like to commend Mr. Hellmund's suggestion to you with all the force I can command, because I believe it now to be imperative that our profession consider well and act immediately upon these matters.

But all is not said when conclusions as to the need for this work are drawn. The most obvious answer to whether such a course as Mr. Hellmund suggests should be a general requirement is yes. The answer to whether it should come early in the engineering work is also yes—but if we insist on being realistic the answers to both of these questions must be qualified in accordance with the teaching resources of the college. Mr. Hellmund has prescribed for his course 2 hours a week for a year. Such a course can be given in that time, and its success will depend directly upon the quality of teaching. Such a brief time, however, forces the teaching quality to such difficult heights that certain practical steps must be taken if such a course is to be a practical success in the engineering college atmosphere. A course such as Mr. Hellmund has described must be taught by an engineer with a background firmly rooted in industrial practice. The teacher to handle the fundamentals of such work properly must assume the role of engineer, accountant, lawyer, and to some extent economist and salesman in turn and all at the same time. The swift transition from one topic to another must be skillfully handled or else a bewilderment in the student is created which to overcome requires a high order of interest on the part of the student (whom you must remember cannot evaluate his interest yet against a particular job in industry as a bench mark). In ordinary English such a course is forever threatened with being christened a "hodge-podge" and losing the respect of the college.

After 5 years' experience in teaching such a course I am firmly convinced that such orientation courses must have a "vehicle" to carry the breadth of material which is included. In our case accounting is used as the vehicle for the first half of the course and economic selection is used as the vehicle for the second half. I discussed this matter briefly last June at the annual meeting of the Society for the Promotion of Engineering Education and in order to conserve time here I should like to refer you to that paper. ("Graduate Work in Engineering and Economics," page 103, *Journal of Engineering Education*, October 1936.) Orientation courses of necessity are like a tramp along a range of hilltops. If a student is inattentive while you are striving to make the panorama that unfolds itself from the various hillcrests mean as much as you can, he is nevertheless quite satisfied if you can place in his basket during the trip something tangible such as an understanding of the rudiments of accounting or a grasp of the principles of economic selection. This philosophy of course results in the need for at least 3 hours per week during the school year to accomplish what Mr. Hellmund proposes to accomplish in 2. The selection of accounting as a vehicle also introduces naturally an expansion of Mr. Hellmund's course further into the financial field than he has suggested. In our case we believe this to be justified in view of the thought which I wish to bring next into this discussion and because of the existence of the third course of 2 hours a week for one half a school year called "manufacturing and production methods," required of all mechanical engineers and emphasizing in considerable detail much of the production and marketing phases included in Mr. Hellmund's course. Our 3-hour a week year course cannot be permitted to duplicate this course to the point of placing a pall upon the interest of the mechanical engineers required to take both courses. There is much more which could be said about the pedagogy and content of courses such as Mr. Hellmund has outlined but time will not permit their treatment. Before closing I am anxious to stress that Mr. Hellmund's suggestion and our practice should be but the starting point of the engineer's training in business and economics.

This thought is treated in full in a recent paper of mine entitled "The Next Step in Engineering Education" (*Wisconsin Engi-*

neer, page 136, April 1937; *Milwaukee Engineering*, page 9, May 1937; also promised publication in an early issue of *Mechanical Engineering*).

The guidance in economic matters afforded by the comprehensive survey course is important, but unless the profession finds some way to continue and organize this guidance, the engineer is going to fail to achieve the economic competence which can only come with a well rounded view of the operation of economic factors in society as a whole. Digging on one's own power will do it—yes—but it takes a much longer time and a consuming interest to drive the process through—and if the engineer is to stand up to the lawyer, accountant, business graduate, and politician early he must be given effective help. In advance of the ultimate 5- or 6-year curriculum which some day seems to be coming for all engineers, the dire need is for a continuation process—a floating curriculum of work which can be partly or wholly taken in either the post graduate or post scholastic period or both.

M. S. Coover (Iowa State College, Ames): Since a measure of responsibility for shaping one curriculum in electrical engineering rests upon me, Hellmund's suggested course on industrial economics and business methods is of more than passing interest. It is an ambitious outline including essential factors of timely importance and I concur in the opinion that some way ought to be found to include a course of instruction in the program of training commonly designed for chemical, electrical, and mechanical engineering students that would be molded around the thoughts set forth in his article.

Inasmuch as it has been my privilege to have organized and taught courses on management, the proposal strikes a receptive chord. These courses, however, were offered by the school of business and were open to seniors in both the school of business and school of engineering, thus creating the sort of tie that I think has many strong points in its favor. One of the restrictions, however, was the necessity to avoid indulging too heavily into engineering terminology and engineering processes that were little or not at all familiar to seniors in the school of business. On the other hand, a course such as Hellmund proposes for engineering students only leaves the field wide open.

To put the proposed course into a reality is not without certain obstacles, principal among which is the element of time. From certain leaders in industry and in engineering education we hear the urge to stick tenaciously to fundamentals, then teach more fundamentals, and then some more fundamentals, with no venture whatever toward specialization. The reasoning being that the employer will by special training shape the man to fit his particular organization.

From other leaders in the same 2 groups comes the urge to include cultural or broadening courses. Still from others comes the declaration that the young engineer's training is incomplete without a thorough grounding in basic principles in the sciences and including industrial economics and industrial relations. Finally there are advocates who believe that the well-rounded graduate should have a reasonably good mastery of fundamentals, a pretty clear conception of economics with all that it implies, and a fair sprinkling of cultural subjects, such as foreign language, history, government, etc. All of these proposals have my hearty endorsement, provided they do not have to be jammed into a 4-year period.

Granting that provision has been made in the curriculum for a sprinkling of elective courses and that a course in industrial economics and business methods is to be made available, best results will accrue if the instructor has had some good sound commercial seasoning so that he can teach, at least in part, on the basis of plain realities and with confidence rather than have to lean entirely upon printed matter. The instructor should be accumulating constantly from the field, and preferably in person, such data on current management problems that he shape into problems for the classroom so as to make them commensurate with the time allotted to the course. One thought to bear in mind is that the capable and interested student should be able to round out the solutions to his assignments with personal satisfaction of mind without having to devote an unreasonable amount of time on them in relation to his other equally important courses.

Personally, I cannot be enthusiastic about 2-hour courses. It is plenty long from Tuesday to Thursday and longer from Thursday to Tuesday. The plan admits of too much lost motion. More effective results, I believe could be obtained from a 4-hour credit course running for one term or one semester. It would include say 3 discussion periods of one-hour duration and one 3-hour laboratory period for analytical and layout problems. Only neat free-hand sketches of layouts would be required.

As for the course content, the chronology of presenting the material and the required amount of coverage to be made each time the course is offered, I would first have implicit confidence in the instructor employed and leave the balance of the program thoroughly flexible, so that he could constantly adjust it to current data procured and to changing economic condition. Since no single textbook could possibly give adequate coverage of course content, free use of library material should be expected of the student.

D. F. Miner (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): Since Mr. Hellmund's paper was written, an opportunity was presented for trying out a portion of the outlined course. A 2-hour one-semester course on economics of using goods was offered for graduate credit under the University of Pittsburgh-Westinghouse plan. Forty-five men, mostly recent engineering graduates, registered, of whom 25 were taking the course for credit toward a master's degree. The subjects covered were the first half of table I in Mr. Hellmund's bibliography.

Although the lecturers were selected from the staff (chiefly engineering) of the Westinghouse company rather than from the University, care was taken to provide men whose major experience had been on the subjects covered. It was felt that the intimate knowledge of the subjects and the practical viewpoint thus presented made up for any deficiency in classroom technique. The lecture method used for many sessions, was supplemented by problems, outside reading and class discussions.

As part of the course, each student was requested to submit frank criticisms of the course both as to subject matter and manner of presentation. Practically all opinions favored the idea back of the course and stated that interesting and useful phases of the subject were covered. Some students said they had previously thought economic problems were solved by executives and they did not realize that even the young engineer must make frequent decisions requiring consideration of economic factors. Many stated they had received no training of the sort before and realized what an important bearing it had on their present and future work. Some stated they thought colleges should present similar work. Others thought they could get more out of such work given by industry after they were on the job. Possibly only a limited number of industries are in a position to organize such classes and that being the case, some general parts of the subjects will, of necessity, have to be covered by college work if it is done at all.

The course was conducted without adherence to specific details of one company's operations. Many commented on this and desired more definite information. While this may be of immediate use in their daily work, it is still considered best to cover each subject in as general terms as possible. As to teaching methods there was a definite desire for more illustrative problems and more class participation through discussions, possibly led by students. The students commented that the personal enthusiasm and specific knowledge of the lecturers vitalized the course in a way not so easily possible with recourse only to textbooks. We were gratified to observe that the students were keenly aware of the importance of industrial relations problems—that a satisfactory handling of people is necessary to the economic success of work with machines and materials.

In the autumn the second semester's work on economics of producing goods will be started and some of the ideas contributed by students will be tried out.

R. W. Sorensen (California Institute of Technology, Pasadena): Mr. Hellmund's authoritative advice regarding the use of some of the engineering student's time during his regular 4-year baccalaureate course for the study of things not strictly technical, such as industrial economics and business methods, is indeed timely. Having advocated and used such a program in the teaching of electrical engineers for more than 25 years, I can certify the fact that men with such training on the whole are better prepared for entry into industry than are students who have taken highly specialized technical courses without obtaining the values which are present in parallel courses involving economics and other humanities.

Of course it is quite evident to all of us that the problem is not simple and there is no clear-cut answer as to just what part of the young engineer's education shall be strictly in the field of his profession and what part shall prepare him to associate without embarrassment with his fellowmen who are not particularly interested in the technique of the mechanical aids to civilization, which are in such common use today.

As a group, engineering educators have recognized the demand for a larger amount of knowledge of economic subjects on the part of some of our engineers by having in some of the engineering colleges curricula designated by the names: engineering economics, management engineering, etc. In my experience, the evils of these courses, as evidenced by the skimpiness of the engineering obtained and the tendency which they have to attract students who cannot make a satisfactory showing in the strictly technical fields, indicate that they are at least dangerous in any set of college curricula, if not inadvisable when they are undergraduate courses.

In fact, I think we should fairly generally refrain from adding to our 4-year courses more and more of the technical content of our profession, which is so rapidly developing, and should tend toward making the 4-year courses leading to the baccalaureate degree general but intensive engineering curricula which include as separate courses, some, but a distinctly limited amount, of the work outlined by Mr. Hellmund.

I am glad to note further that the paper under discussion presents material which can be used to a large extent by men teaching the strictly technical engineering courses pertaining to electrical machinery and does not of necessity require for its inclusion in an engineering curriculum the setting up of many separate courses dealing with economics only. For example, when a class is studying the technique of electrical-machinery design, it is entirely possible for the teacher to point out factors which influence design because of cost of materials, labor, test, inspection etc. Also, it is very easy to point out how designs may be modified without much sacrifice in electrical characteristics so that standard frames may be used for several machines.

My particular suggestion, therefore, would be that the teachers of engineering in discussing the design and operation of electrical machinery with students, supplement the technical phases of design and performance by discussion of the economic factors which influence the construction and operation of the machine and also by showing how the use of the machine influences the economic life of those who use it. In fact, it seems somewhat surprising to me that any teacher of electrical machinery can avoid so doing, because I recall quite distinctly the fact that one of the students in the first class in dynamo-electric machinery which I ever taught said to me one day: "Well, all of these facts are very interesting, but you seem to indicate that the final decision as to whether a machine will be built and installed and as to how it will be built is largely a matter of dollars and cents rather than electrical phenomena." That man became an outstanding sales engineer. But lest I lose caste with the technical men of my profession, may I also add that one of his classmates received a very different message from the things taught in the class and went out from the college with a desire to be a very skilled technician who reveled in the theory of the electrical circuit.

R. E. Hellmund: The extent of the discussion of my paper and the generally favorable reaction is very gratifying in that it definitely indicates an increasing interest in the subject on the part of the teaching profession. In some of the discussions it is pointed out that it will be difficult for the colleges to obtain suitable material for class work, particularly problems, and that it will be even more of a problem to find instructors prepared to carry on a course of this nature. It is of course true that some difficulties will be encountered in any new undertaking, but I do not feel that those arising in this particular work will be insurmountable. The only practical solution therefore seems to be to get started and to improve both the material and the teaching personnel as time goes on.

I know that a number of efforts along lines somewhat similar to those outlined in my paper have been under way at various schools, such, for example, as described by Putnam for the Case School of Applied Science, by Ayres for the University of Wisconsin, Coover for Iowa State College, Lovell for Ann Arbor, and others. The relative success and favorable reception of these efforts are in themselves evidence that something of value can be accomplished. It is quite natural that these efforts, each started independently of the other, should differ, and also that they should differ in certain respects from the course suggested in my paper. As a matter of fact, I believe that the trying out of certain variations in anything that is comparatively new is very essential for arriving at the most successful final solution. My purpose in giving such a detailed outline was chiefly to assist those who wished to undertake some new work of this character and who might find it difficult to obtain appropriate material. In making variations from the suggested plan, however, I believe that the proposed comprehensive character of the course should not be lost sight of and that some phases of the work which have been neglected in the past in courses of this nature should be given careful consideration. As an illustration of this, the combination of courses mentioned by Professor Ayres would permit the use of much of the material outlined in my paper, but the titles of the courses in themselves do not indicate that sufficient attention will be given to such important matters as marketing, stock-keeping, obsolescence of stock, and standards. Again, the practice suggested by Professor Lovell of considering economic matters in connection with the course on the generation and distribution of power, while having certain advantages, is not likely to afford an opportunity for stressing the very important subjects just cited.

Some of the discussions bring up the question of whether the proposed course should be given during the four-year curriculum or as postgraduate work. Mr. Miner in his discussion gives a logical answer to this when he points out that since only a limited number of industries are in a position to organize classes, the work must necessarily be given in the regular college course if all of the students are to profit by it. I furthermore agree with Professor Ayres to the effect that in order to put strength into this move, the start must in general be made in college. This does not preclude the desirability of those schools located in industrial centers giving such material in a postgraduate course; in fact, plans along this line are now under way. Some of the discussions stress the fact that colleges should deal essentially with fundamentals, but it is also pointed out, and quite properly, that the fundamentals of economics are as important as other fundamentals. Professor Malti in particular points out that the principal purpose of education is to develop certain qualities and habits in the student. I myself have made similar statements too often to take any exception to this. However, even though this is very true, we must not overlook the equally true fact that engineers, like men of other professions, must have a great deal of knowledge if they are to carry on their work efficiently. It would be very foolish to ignore this fact entirely during the four-year course, and the present practice of imparting to the student as much knowledge as practically possible in addition to developing within him the qualities outlined by Professor Malti is very effectual. The only question then that can be raised is that of whether certain kinds of knowledge should best be acquired before or after graduation.

I have not commented in full on all of the discussions, but it is obvious that the various viewpoints of teachers of many years' experience, such as Professor Sorensen and others, as well as the experiences cited by Mr. Miner, should be given full consideration by those interested in the subject.

Per-Unit Quantities

Discussion and author's closure of a paper by Irven Travis presented for oral discussion at the education session of the summer convention, Milwaukee, Wis., June 22, 1937, and scheduled for inclusion in a special supplement to the annual TRANSACTIONS for 1937.

M. G. Malti: See discussion, page 1400.

B. R. Prentice (General Electric Company, Schenectady, N. Y.): Mr. Travis has made a timely and valuable contribution to the literature of engineering education in his brief and clear exposition of per-unit quantities. I agree with him that per-unit representation is "confusing to the average student" and for another reason in addition to those he has given. Students are often introduced to per-unit at the same time that they take up the study of some new machine or subject, frequently, synchronous-machine theory. Added to the fresh concepts of the new theory are the novel ideas of per-unit, multiplying the confusion. Mr. Travis has aptly applied per-unit to well-known problems.

In developing the "theorem in dimensional analysis," it is tacitly assumed in equation 16 that the parameters and variables can be expressed in terms of not more than 4 fundamental dimensions, length, mass, time, and electric charge. It is then properly shown that "It is never possible to assign more than 4 independent bases." However, it is inferred that this last statement applies to physical problems generally instead of the limited class of problems covered by the tacit assumption. Obviously, if 3 or

5 fundamental dimensions had been assumed, the mathematical derivation would have resulted in a maximum of 3 or 5 independent bases, respectively. In general, pure mathematical proofs of the number of independent dimensions in other than specific problems cannot be given as dimensions are inherent physical things, and rest on experimental laws and arbitrary definitions. In one important class of problems, it is convenient and desirable to include a fifth fundamental dimension, temperature. Such problems are those involving heat flow as well as mechanical and electrical phenomena. I believe that, in such problems, the dimension temperature (or its substitute) can only be eliminated by recourse to kinetic theory which is outside the realm of most engineering problems.

The "theorem in dimensional analysis" is valuable for finding the number of independent bases and determining which specific ones are independent in any actual problem provided one knows the independent fundamental dimensions involved from physical reasoning.

Irven Travis: Mr. Prentice is entirely correct in his statement that the conclusions in the "theorem in dimensional analysis" apply to the limited class of problems described by the 4 fundamental dimensions; length, mass, time, and electric charge. In a preliminary draft of the paper, the theorem was set up for a system of n independent dimensions; this was changed in an effort to simplify the derivation as much as possible for student consumption.

The general rule for assignment of bases is: Independent bases may be assigned to any group of quantities, providing the rank of the matrix formed by the exponents in the dimensional formulas for these quantities is equal to the number of bases to be assigned. It is evident that in the matrix described, the number of rows is equal to the number of bases, and the number of columns is equal to the number of fundamental dimensions. The greatest possible number of independent bases is, therefore, equal to the number of fundamental dimensions.

An error has been called to my attention by Mr. J. E. Hobson. In figure 2, under receiver, 10,000 kw should read 10,000 kva.

Fundamental Concepts of Synchronous Machine Reactances

Discussion of a paper by B. R. Prentice presented for oral discussion at the education session of the summer convention, Milwaukee Wis., June 22, 1937, and scheduled for inclusion in a special supplement to the annual TRANSACTIONS for 1937.

M. G. Malti (Cornell University, Ithaca, N. Y.): These papers are in a class which the Institute might well foster. They are admittedly expository and contain recent developments in electrical engineering presented in a new, clear, and concise form which the student and the average engineer can read and thoroughly understand and enjoy. The committee on education, in sponsoring these papers, has injected into the Institute an activity the need of which has long been felt by the Institute membership in general and by educators in particular.

A New Magnetic Flux Meter

Discussion and author's closure of a paper by George S. Smith published in the April 1937 issue, pages 441–5, and presented for oral discussion at the instruments and measurements session of the summer convention, Milwaukee, Wis., June 22, 1937.

R. F. Edgar (General Electric Company, Schenectady, N. Y.): Professor Smith's paper describes an instrument which should prove useful in many applications. Two achievements have been realized in the development. The first is the development of an instrument employing bismuth but having a zero indication which is not affected by temperature changes. Lack of this feature has been one of the biggest objections to the use of the bismuth spiral as a means of measuring magnetic field strength. The second lies in the ability of the instrument to measure flux densities in the range below 1,000 gauss.

The calibration curves of figure 3 show a very nearly linear characteristic from a full-scale value down to about 2,000 gauss. Are calibration curves for the lower ranges, say for a full scale value of 2,000 gauss, similar in shape, or do they curve to a greater extent throughout the range? Is the zero adjustment as stable for this low range as for the higher ones? What does Professor Smith consider to be the lowest range which it would be feasible to design the instrument for?

This method of measurement differs from that of using a search coil and galvanometer in that the latter is definitely directional and, in a uniform field, measures only the component perpendicular to the plane of the coil. Does the bismuth spiral exhibit any difference in its action which depends upon the direction of the magnetic field? Would the action of a straight piece of bismuth conductor be the same in a longitudinal field as in a transverse field?

G. S. Smith: The questions by Edgar and Sprague are quite opportune since the answers to some of them had not been discovered until after the paper had been published.

A meter just recently completed, was so made that 3 exploring bridges could be used with the same meter equipment. Table I shows the variation in design in these bridges.

Bridge number 3 was the most sensitive and was calibrated for a full-scale range of about 2,100 gausses. Bridge number 1 was calibrated for a maximum range of 22,000 gausses. It is evident that any of the bridges could be calibrated for any upper limit within the range of the calibrating equipment.

Answering Mr. Edgar's questions first, I would say that in the calibration curves for the higher ranges, the straight line portion of the curve occupies a little greater per cent of the full scale on the meter than in the lower ranges.

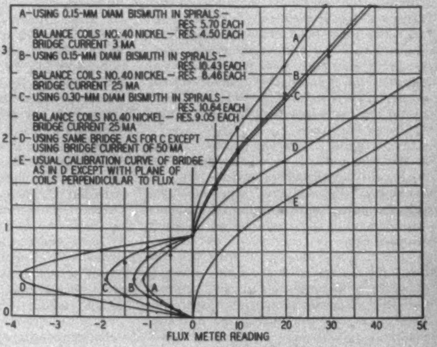


Figure 1. Effect of holding plane of bridge coils parallel to magnetic flux

If an accurate zero adjustment is obtained it is very stable for all ranges on the meter. It is evident, however, that when using the lower ranges, the greater sensitivity available will cause a greater displacement from zero if any temporary resistance changes take place. Such variations can be caused by quick changes in temperature in one or more of the coils above or below the remainder. In the normal use of the meter such differences

Table I

	Number 1	Number 2	Number 3
Diam. of bismuth wire used—millimeters	0.15	0.15	0.30
Approx. resistance of each spiral—ohms	5.7	10	10
Diameter of spiral—millimeters	5	7.5	15

usually exist for only a few seconds, if at all, after which the true zero position of the meter is restored.

It is rather difficult to state the lowest feasible range for such an instrument. For a portable instrument, using the small inexpensive type of meters, and a bridge diameter of about one centimeter, a full scale range of about 2,000 gausses would probably be as low as could be expected. By using a more expensive meter, as the flux-reading meter, or more material in the bridge, or both, the full scale range might be reduced to 1,000 gausses or less. By using a sensitive galvanometer, in which case the meter would no longer be portable, the full scale range might be reduced well below 500 gausses. A vacuum-tube amplifier might also be used, though little has been done thus far in attemping this.

Previous researches have shown that less change in the resistance of bismuth takes place in a longitudinal field than in a transverse field. The curves *A*, *B*, *C*, and *D*, in figure 1 show the results of calibrations made when holding the plane of the spirals parallel to the magnetic field, while curve *E* is for the same bridge as used in *D* except holding the plane of the spirals perpendicular to the magnetic field. For low flux densities the readings for *A*, *B*, *C*, and *D* are negative, and for higher values displaced vertically from the usual calibration curve as in *E*. It should be noted that the scale in figure 1 is greatly magnified on the negative side. This negative effect may be due to some characteristic of the nickel wire used as balancing resistors in the bridge. Careful resistance measurements on a plain bismuth spiral placed first with its plane parallel to, and second, perpendicular to, the magnetic field, showed less change in the resistance in the first position than in the second, but showed no tendency toward a negative or lowering of the resistance at any flux density.

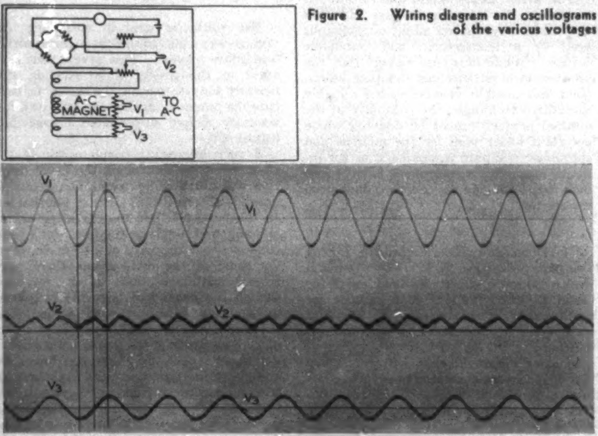


Figure 2. Wiring diagram and oscillograms of the various voltages

It is interesting to note that the changeover from negative to positive occurs at about the same value of flux density regardless of the size of wire or resistance used in the bismuth spirals. This might also be an indication that the negative effect is due to some characteristic of the nickel rather than the bismuth.

Mr. Sprague inquired about the use of the flux meter in alternating or transient fluxes. The bridge does give a reading for an alternating magnetic flux, but thus far too little has been done in this field to make any more definite statements.

A crude, but sensitive oscillograph vibrator was constructed and used as the flux indicator V_2 in the bridge circuit as shown in the wiring diagram in figure 2. Thus the V_1 wave in the oscillogram shows the flux variation due to an alternating magnetic field caused by the voltage shown in V_1. V_3 shows the voltage induced into a separate coil about the same field. As will be noticed in the wiring diagram, it was necessary to balance out a small component of alternating voltage induced into the bridge circuit since it apparently was not entirely noninductive in construction. Since the vibrator used was very crudely constructed, and not oil damped, it is scarcely feasible to attempt to explain the harmonics shown since they might have been due partly or wholly to other causes than flux variations.

Figure 3 shows the results of using the meter to measure the variations of the flux density in the air gaps of motors and generators. In these curves only the maximum and minimum values were measured, and the remainder of the curves sketched in. With a suitable instrument, the complete curves, accurate at every point, could be very quickly and easily obtained by photographic or curve drawing methods.

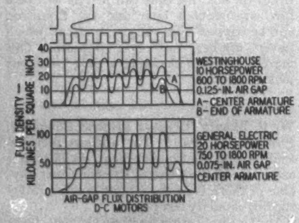


Figure 3

A New High-Speed Cathode-Ray Oscillograph

Discussion and authors' closure of a paper by H. P. Kuehni and Simon Ramo published in the June 1937 issue, pages 721–7, and presented for oral discussion at the instruments and measurements session of the summer convention, Milwaukee, Wis., June 22, 1937.

J. H. Hagenguth (General Electric Company, Pittsfield, Mass.): The authors have given a very good description of the new oscillograph. One of these oscillographs has been in use in the high-voltage engineering laboratory, with which the writer has been connected, for the last year and a half. This oscillograph represents a great improvement in the oscillographic art chiefly from a mechanical point of view.

The compactness of the assembly combined with accessibility of the component parts permits easy handling of the oscillograph and provides for the least amount of trouble. The adaption of the completely sealed cathode-ray tube eliminates all delays inherent to the continuously evacuated type, resulting in a considerable saving of time. Several improvements in the tube design might be desired: First, the curvature of a d-c calibration line at the higher calibration voltages might be eliminated (see figure 4 of paper), second, the focusing of the beam might be improved, to give a more uniform and sharp definition of the beam on the front and on the tail of waves (figure 5 of paper).

Considering the low cathode excitation voltage of only 15 kv, as compared to 60 to 80 kv of the usual cold-cathode continuously evacuated oscillograph, the writing speed is excellent. At the higher rates of speed required for front-of-wave testing at 1,000 kv per microsecond or higher, the record on the film sometimes does not reproduce well on a blueprint, but the necessary data can be taken from the film directly so that the oscillograph can be used for all testing, which at present is required for high-voltage work.

The easily varied cathode-voltage supply enables the use of the oscillograph in connection with the transient analyzer for determining wave shapes for transformer impulse testing.

Otto Ackerman (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): In the first part of their paper the authors give a very clear and interesting review of the history of the cathode-ray oscillograph. They relate how, with the development of high-voltage metal oscillographs with internal photography, the art of measuring electrical transients has come to its height and has actually reached its limits. It was with instruments of this type that by far the biggest part of all impulse testing and research in the last 10 or 12 years has been carried out, which made the cathode-ray oscillograph an invaluable tool in science and industry. Since it is the very essence of our endeavor as engineers to obtain certain results in the simplest and most economical manner, the development on cathode-ray oscillographs has of course been continued, although types are already available which have as high a recording speed and accuracy as can be needed. It is, therefore, quite appropriate that any new appearance in this field be scrutinized as to whether it comes up to the standards in performance which the industry has already learned to expect.

One extremely important feature which has helped to make the cathode-ray oscillograph such a remarkable instrument is its instantaneous response to an external impulse. It is not clear why, in this new type, a time lag of about 20 microseconds is introduced before the timing sweep is started. Should the formation of the grid-controlled cathode beam require any such interval which practically excludes this type from the use of the recording of random phenomena?

Another feature which it appears to the writer entails many hidden difficulties, is the use of a great number of small sphere gaps. Five such sets are shown in figure 3. Their spacing can be only of the order of $^1/_{16}$ inch. They obviously need a great deal of attention for constant operation.

Whether it is the time lag in the formation of the beam or the variations in the system of small gaps, it appears to be necessary to definitely start the oscillograph before the surge generator or, in other words, start the surge generator by means of an impulse from the oscillograph.

Since the voltages available at the oscillograph circuit are comparatively low, an intermediate impulse amplifier must be added (see figure 7).

Regarding the oscillograph records themselves, the obtainable accuracy in voltage measurements is, of course, another important feature. It is partly determined by the ratio between the picture size and the width of the recording trace. Are the records as published about full size?

Of equal importance in this respect is the uniformity of deflection or calibration. The upper lines of the calibration record in figure 4 are quite definitely curved. This accentuates another problem in oscillograph design: The potentials applied to the deflecting plates influence the speed of the electrons passing between them. If the deflecting potentials are not negligible compared with the cathode voltage, the electron speed suffers changes which result in nonuniform deflections and are partly responsible for pattern distortion.

These features could be expressed in terms very much like those of speed and focal length when speaking of photographic cameras, which serve to compare their quality. If such terms were already used with cathode-ray oscillographs, they would establish some sort of rating for this type of equipment.

The writer, furthermore, likes to suggest that the apparent misprint in reference to a film speed of 500 feet per second be corrected. To unsuspicious readers, this figure might not seem extravagant with an instrument where one deals with fractions of microseconds and hundreds of kilometers per second of writing speed.

The writer finally would like to take exception to the inference on page 722, that the vacuum system on metal oscillographs need be a troublesome and unreliable feature. While it is true enough that the production of satisfactory pumping equipment and air-tight vessels requires a highly specialized technique, the reliability of the finished product cannot be doubted where porcelain solder seals by the millions and automatic pumping equipments, as for instance in mercury arc rectifiers, have proved their dependability in countless industrial applications.

R. J. Donaldson (Commonwealth Edison Company, Chicago, Ill.): The Commonwealth Edison Company has had one of the General Electric type *HC*-15 cathode-ray oscillographs for several months. Some of our operating experiences may be of interest to others.

In using the oscillograph with the rotary film drum, to make records of events occurring over a period of several cycles of a 60-cycle wave, it is sometimes desirable to have the cathode-ray beam stay on for an accurately predetermined time. If it is on for less time than this, the record may be incomplete, if it is on for more, there are unnecessary traces on the film.

The duration of the beam is determined by the time required for an adjustable capacitor to partially discharge through a Thyrite resistor in series with the anode circuit of a thyratron tube. Due to the temperature characteristics of this tube, it is not usually possible to be sure of the exact number of cycles the beam will be on. The duration of the beam is also affected to some extent by changing from one thyratron tube to another. It was thus desirable to have some means of determining the duration of the beam just prior to the making of an oscillographic record.

This was done indirectly by measuring the product of beam current and time, or IT. A capacitor was connected between the cathode-ray tube anode and the oscillograph case to which the anode is normally grounded. The potential built up on this capacitance by the beam current flowing for time T is almost directly proportional to the duration of the beam. This is true where the capacitance is made sufficiently large so that the potential built up on it is very small compared with the cathode-ray tube voltage. The capacitor potential was $E = IT/C$ where I is the beam current, T the duration of the beam, and C the capacitance in series with the tube anode. The potential on the capacitor was measured with a high-resistance d-c voltmeter. Each volt represented so many milliseconds beam duration, or so many cycles of a 60-cycle wave. If the same beam intensity and cathode-ray tube voltage were used, the meter could be calibrated directly in time or cycles duration.

For the *HC*-15 oscillograph the beam current at maximum intensity with 15 kv on the cathode-ray tube is about $^1/_5$ milliampere. The duration may be adjusted for various times up to about 20 cycles of a 60-cycle source or $^1/_3$ second. The capacitance used was 2 microfarads. This gave a value of

$$E = \frac{IT}{C} = \frac{0.0002 \times .33}{2 \times 10^{-6}} = 33 \text{ volts}$$

The voltmeter used in measuring this voltage was a microammeter in series with a 5-megohm resistor. This gave a time constant to the circuit of 10 seconds, sufficiently long to permit the meter to indicate the potential on the capacitor with fair accuracy before appreciable charge had leaked off.

A very interesting characteristic of the thyratron tube controlling the beam duration was noted while operating the oscillograph with the rotating drum film holder. In this particular test the thyratron circuit was adjusted to release the beam for a total time of about 20 cycles of a 60-cycle wave. On some of the oscillograms there were several missing sections in the wave as though the beam had been blocked for a moment and then released again. The thyratron tube can be tripped from either of 2 3-electrode spark gaps in the initiating circuit. The first gap is tripped by applying a few thousand volts to the middle tripping electrode from a 60-cycle transformer and this gap in turn trips the second gap a few microseconds later, starting the time sweep. Occasionally the 60-cycle potential on the middle electrode caused several successive sparks to the gap electrode to which the thyratron grid was connected while the beam was still released. If the impulse from these sparks was negative the beam was blocked until a positive impulse occurred releasing the beam again. This sometimes occurred several times during the 20 cycles being recorded. At first this appeared quite unusual, for the anode current in a thyratron is usually considered to be independent of grid potential after the tube is tripped. However, in an article in the December 1936 issue of ELECTRICAL ENGINEERING, Herbert J. Reich of the University of Illinois points out that the grid of a thyratron may be used to stop, as well as start, the flow of current provided the current is small.

The remedy for the interrupted beam, once the cause was found, was simple: readjust the gap to a spacing such that it will spark over only once during the recording time. Actually the solution was even more simple. When using the rotating drum the starting time can just as well be a few microseconds later and the thyratron can be tripped from the sweep circuit which never applies but one impulse. This merely involves changing a plug from one jack to another.

W. F. Skeats (General Electric Company, Philadelphia, Pa.): The authors mention that several multiple-element oscillographs are in use in the General Electric Company. One of these is in the circuit-breaker interrupting capacity test plant.

In this application multiple elements were desired partly to observe phenomena on the

3 poles of a 3-phase breaker and partly to observe the operation of different parts of a special circuit for determining the performance of breakers at short-circuit power beyond that available at the testing plant. The speed required was moderately, but not extremely, high, the maximum frequency anticipated being about 200,000 cycles, but on the other hand a long record was necessary as it was desired to observe phenomena occurring two or three hundredths of a second apart. It was also desirable to have records available promptly after each operation with a minimum of delay before the instrument would be ready for another record.

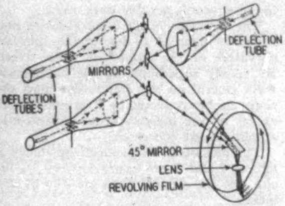


Figure 1. Optical system of cathode-ray oscillograph

Many of the unique features of the design will be evident from a diagram of the optical system which is shown in figure 1. Three sealed glass deflecting tubes with fluorescent screens are used. These deflect the beam in one dimension only giving a deflection proportional to the quantity being measured. A lens focuses the light from these screens upon a film mounted on the inside of a rotating drum. One mirror is used to make the necessary bend in the light beams on the inside of the drum, and in order to obtain compactness of the field of vision and reduce its size 2 deflecting tubes are placed on one side and one on the other of a central axis, individual mirrors being placed on this axis to reflect the three light beams into the same plane. These latter also provide an adjustment to line up the 3 spots with respect to each other on the film.

Figure 2. Section of cathode-ray oscillogram

The film was placed on the inside of the drum in order to make high peripheral speeds available without the introduction of awkward clamping means or the possibility of breaking or loosening of the film on account of expansion resulting from its own centrifugal stresses.

The drum is 12 inches in diameter, and rotates at a maximum speed of 10,000 rpm. This gives a time scale of 6 microseconds per millimeter, stretching out one cycle of a 200,000-cycle wave over 0.8 millimeter. With a reduction of about 5 to 1 in the optical system, a sharply defined curve is obtained which can easily be read at this spacing.

Figure 2 shows part of a record obtained with this oscillograph indicating the voltages attendant upon the interruption of the last two phases of a 3-phase-to-ground fault on an ungrounded generator. The upper and lower traces are the voltages across the 2 poles of the breaker clearing at the time of the record and the center trace shows the voltage induced the phase which had cleared previously.

A. T. Sinks (General Electric Company, Lynn, Mass.): We have had in our laboratory at the West Lynn Works for about 8 months a cathode-ray oscillograph of the type described in this article. During this period the oscillograph has been in use at least 50 per cent of the time testing instrument transformers and has been of great value to us in designing transformers for higher impulse-voltage strengths.

I do not mean to imply that impulse testing was made possible only by this new oscillograph, as before its advent we made impulse tests for a number of years using the old type of oscillograph in which the film was inside the tube, and for the most part results obtained with this instrument were very satisfactory and we made quite valuable improvements in instrument transformer design on the basis of these results.

However, in our work, the new oscillograph has demonstrated its superiority over the old type in a number of ways. In the first place, with the new design, as the authors state, the time of pumping a vacuum and any question of having the right vacuum after replacing the film is eliminated. In the second place, one can see the wave at the same time a picture is taken. On the old type this was not possible and there was no way of knowing what happened when a surge was recorded on the film until the film was developed. When, as frequently occurs, one wishes to know what has happened before going further, it is obviously very much more convenient to be able to have some knowledge of what occurred without waiting to develop films and disassemble apparatus.

Another point of interest in the new oscillograph is that we have found the calibration of the cathode-ray tube to be very constant and consistent.

Since the whole apparatus including trip circuits and calibrating devices is co-ordinated in one design and made in one unit the operation of the apparatus is simplified.

When all is taken into account, we, therefore, feel that the new oscillograph design represents a valuable advance in the art.

P. R. Benedict (nonmember; Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): The development of this new self-contained, portable oscillograph is a noteworthy contribution to the technique of impulse testing. This device fills a need for a laboratory instrument which bridges the gap between the low-voltage cathode-ray oscillograph and the cold-cathode 60-kv constant-beam oscillograph. Two features of the instrument which are new are the simultaneous viewing and recording arrangement and the cathode beam initiating unit. In regard to the cathode-beam initiating system I would like to ask the authors what beam current is used in the tube. How is it measured for the short time the tube is in operation?

In recent years, more and more stress has been laid on front-of-the-wave testing and it has been necessary to improve the existing cold-cathode instruments. All reliable impulse data must be sealed from recordings of actual impulses applied to the test piece. Oscillations on the test wave tend to decrease the density of the trace and make suitable recording difficult. In order to get readable, reliable records, all spurious oscillations must be eliminated from the system. It has been my experience that nearly all spurious oscillations come from poor grounding arrangements. Grounding the test generator at only one point helps a great deal. All divider cables should be grounded at the generator ground. A copper-braid sheath over the lead sheath of the divider cable also helps to reduce superimposed oscillations on recorded test waves. The divider cable sheath should be insulated from ground over its whole length. Short heavy ground connections should be used at both ends of the cable. The authors show no damping resistors in the timing plate leads to the cathode ray tube. Such resistors placed at the timing plates help to cut out inductive pickup from the voltage leads and other parts of the oscillograph system. A resistance value of 3,000 ohms is about right. The timing calibration should be made with the resistors in. The unit described by the authors is very well shielded as the oscillograms show.

The oscillograph tube of this article uses electrostatic concentration methods for producing an intense beam. The cold-cathode instruments are much harder to focus in this way but satisfactory progress has been made in this country and in Europe. Field control at the cathode seems to offer the best solution of concentrating the beam electrostatically. The use of a magnetic concentrating coil between the cathode and anode, so placed that the beam is focused on the anode hole, 0.025 inches in diameter, improves the recording speed materially. I would like to ask the authors what the recorded trace width is. In high voltage it is imperative that the beam be intense but narrow. Assuming a trace width of 0.1 inch, and a deflection of 2 inches, the trace width is 5 per cent of the recorded voltage. Such a wide beam introduces errors in scaling oscillograms and while the recording speed may be increased by using a large diameter spot, a trace width of about 0.040 inches is desirable.

What is the actual deflection in inches of the records of figure 5 and figure 6? Also, what is the approximate voltage of figure 6? In high-voltage recording it is desirable to use about a 3-inch voltage deflection for satisfactory accuracy. A time deflection of about $2^{1}/_{2}$ inches per microsecond is also necessary for wave-front testing. The testing of lightning arresters and all apparatus at short time to flashover values require such deflections for satisfactory scaling, especially where time to flashover curves are desirable.

The rotating-drum type of camera can also be applied to the cold-cathode type instrument and the loss of time due to re-pumping after each film is more than offset by the excellence of the record. In the modern high-voltage beam oscillograph 8 to 10 minutes are consumed in pumping to working vacuum after a film change. When taking time to break down curves, using roll film, as many as 150 records are taken on a 6-exposure film. The cold-cathode instruments may be used to cover the range of 10,000 microseconds to the shortest times obtainable in surge-generator circuits. Calibrations are permanent and accurate to about 1 per cent. While the authors state the writing speed of 10 inches per microsecond, the requirements of wave-front testing and short time to breakdown phenomena are such that 50 inches per microsecond is desirable in an instrument used for the collection of pertinent impulse data.

H. P. Kuehni and **Simon Ramo:** Mr. Ackerman's comments and questions about the new cathode-ray oscillograph are indeed very interesting and also highly pertinent and the authors welcome this opportunity to discuss here briefly some of the details which might not have been sufficiently clearly brought out in the paper.

The second, third, and fourth paragraphs of Mr. Ackerman's discussion are quite closely related from the point of view of the oscillograph design features and they may be answered as follows.

In order to serve as a fundamental background for the general discussion, it may perhaps be well here to state the basic requirements which guided the design of the new oscillograph.

(*a*). The oscillograph must satisfy practical impulse testing requirements. It must be capable of recording standard impulse testing waves.

(*b*). The oscillograph records shall show a portion of the sweep (zero line) before the wave record begins so as to obtain a full wave record. This result is to be obtained without the use of delay cables. Therefore, this feature makes it necessary to initiate the oscillograph sweep before the appearance of the impulse wave at the oscillograph deflection plates.

(*c*). In view of (*b*) above, the oscillograph shall include means for initiating an impulse generator and shall include proper timing equipment to release the cathode-ray beam, to start the sweep and to initiate the impulse generator at the correct time.

(*d*). The oscillograph shall also be capable of recording random phenomena whereby the cathode-ray beam and sweep are initiated by an incoming voltage impulse. For this application the response must take place within a fraction of one microsecond.

For reasons of economy and also to arrive at a compact design the internal oscillograph initiating circuits were limited to 7.5 kv with respect to ground, and 3 electrode gaps were selected to initiate these circuits. It is quite natural that Mr. Ackerman should question the reliability of low-voltage gaps of this kind and the authors share his skepticism in a general way. However, by the use of effective artifices the performance of these gaps was rendered reliable in service without necessitating undue critical gap adjustment. Tests have shown that small gaps of the type used may be made to perform very uniformly by ultraviolet light irradiation. The necessary gap irradiation is obtained from an auxiliary circuit and it is the main function of the primary initiating circuit, which is tripped by the 60-cycle transformer and push-button shown in figure 3, to supply the needed ultraviolet light at its spark gaps. As figure 2 shows, these gaps are mounted very close to the sweep-initiating-unit gaps. The time performance of the auxiliary circuit gaps obviously need not be accurate.

Inasmuch as a primary initiating circuit was used, it was decided to initiate with it also the cathode-ray beam. The time delay of approximately 20 microseconds, introduced between the primary initiating circuit and the sweep circuit, was quite arbitrary and was admittedly originally introduced to give the thyratron tube and the cathode-ray tube ample time to establish the cathode-ray beam before the initiation of the sweep. However, it was soon found that this precaution was quite unnecessary, because the cathode-ray beam could be initiated in a small fraction of a microsecond by applying a sharp voltage impulse to the thyratron grid. Nevertheless, the resistance between *M* and the sweep circuit midsphere was retained to prevent a voltage impulse of large magnitude at *M* and the thyratron grid *L* when the sweep circuit midsphere is tripped by an incoming voltage impulse applied at *O* as shown in figure 7. Also, this method of primary beam initiation provided a convenient means of initiating the cathode-ray beam in rapid succession for beam focusing purposes without having to wait 20 or 30 seconds for the sweep-circuit capacitors to charge through a high resistance.

Referring to the diagrams of figure 3 and figure 7, when the oscillograph is to be used for recording random phenomena, provisions are made, by means of a flexible lead and plug, to connect the thyratron grid lead at *O* of the sweep circuit instead of at *M* of the primary initiating circuit. In this case the incoming voltage impulse through *Q* is then used to initiate the gaps of the sweep circuit and the cathode-ray beam. By using a fairly large incoming momentary voltage impulse of, say, 50 kv, which is usually readily available in this type of recording, ultraviolet gap irradiation as described above is now not needed. Thus, it is not necessary to start the oscillograph before the surge generator. However, it is generally advisable to do so, whenever the impulse generator initiation is under control, as is the case in impulse testing and when a complete wave record is desired without the use of an artificial delay of the arrival of the voltage wave to be recorded.

In figure 7 there is shown between the oscillograph and the impulse generator an intermediate initiating circuit which was used, as pointed out by Mr. Ackerman, to amplify the 7.5 kv output from the oscillograph. Since the publication of the paper a simple inexpensive air-core type of transformer was developed to take the place of this unit, whereby the voltage of 7.5 kv is transformed into a voltage of 70 or 80 kv suitable for initiating directly the impulse generator. The polarity can easily be changed by simply reversing the output leads. This method has proved to be highly successful and precision timing was obtained.

The performance of this type of oscillograph in impulse testing work has been excellent and as many as 120 consecutive impulse records per day were taken.

The curvature of the d-c calibrating lines shown in figure 4 is due to the spherical curvature of the fluorescent tube screen. By simply superimposing the oscillograph wave records on this calibration chart this slight curvature should be of no consequence as far as the measurements of deflection amplitudes are concerned.

The oscillograph reproductions shown in figures 4 and 5 are approximately 1/2 full size and the original films are 3 1/4 by 4 1/4 inches.

Mr. F. R. Benedict's interesting comments relating to the technique of building impulse testing circuits free from spurious oscillations agrees well with our own laboratory experience.

The exact magnitude of the beam current in the cathode-ray tube has not been measured. However, test evidence obtained by observing, by means of a cathode-ray oscillograph, the voltage drop across a suitable resistor in the cathode circuit indicated that the beam current is approximately one milliampere when the beam intensity control is adjusted to maximum at zero control grid bias.

The width of the recorded trace of the records shown in figure 5 is approximately 3/32 inch where it is widest. The width depends on the cathode spot motion, it being somewhat larger when the cathode spot is moving slowly. However, the high-vacuum type of cathode-ray tube with electrostatic control grids leads itself to a very fine beam-intensity control.

The amplitude deflection of the records shown in figure 5 is approximately 1 1/8 inches. The records of figure 6 were taken with a small camera giving a record about 1/5 full size. In our laboratory we project these records for analysis on a graduated screen by means of an enlarging camera with excellent results.

Mr. R. J. Donaldson's discussion refers to the use of the new oscillograph for rotating film drum recording. In the transient recording with stationary film and cathode beam sweep, the slight erratic shut off of the thyratron tube is, of course, of no consequence because the cathode-ray beam is already swept off the screen when the beam is finally shut off. Mr. Donaldson has made a very interesting contribution in the form of his current times time number of cycle indicator.

The authors wish to rectify here an omission in the bibliography of the paper and attention is here called to an excellent paper by Messrs. K. B. McEachron and E. J. Wade entitled "Study of Time Lag of the Needle Gap" published in the AIEE TRANSACTIONS, volume 44, pages 832–42, June 1925. This paper is one of the earliest describing the application of the high-voltage internal-photography cathode-ray oscillograph to practical electrical engineering problems.

Sixty-Cycle Calibration of the 50-Centimeter Sphere Gap

Discussion and authors' closure of a paper by C. S. Sprague and G. Gold published in the May 1937 issue, pages 594–6, and presented for oral discussion at the insulation co-ordination session of the summer convention, Milwaukee, Wis., June 22, 1937.

J. R. Meador (General Electric Company, Pittsfield, Mass.): The authors have described what appears to be a very practical method of measuring high a-c voltages that lends itself particularly well to calibration purposes.

While making 60-cycle spark-over tests on grounded sphere gaps ("Calibration of the Sphere Gap," J. R. Meador. ELECTRICAL ENGINEERING, June 1934) in 1933 at Pittsfield, the writer had occasion to take a few check points on a 50-centimeter isolated sphere gap. The results were not published at that time due to the small number of spacings tested and to the fact that only one size of sphere was used. Since the calibration points checked the values in Standards Number 4 to within 2 per cent to 3 per cent, there did not appear to be an urgent need for further investigation. The more complete investigation conducted by Messrs. Sprague and Gold seems to indicate that a slight revision of Standards Number 4 for isolated spheres would be desirable.

The calibration points that were obtained by the writer are compared in table I with those for nonirradiated spheres given by the authors and with Standards Number 4.

It will be noted that the maximum difference between the Pittsfield points and those of the authors is 1.8 per cent which is very good agreement for measurements of this nature.

Table I

Sphere-Gap Spacing (Centimeters)	Spark-Over Voltage (Kilovolts Crest) Nonirradiated		
	Meador	Sprague and Gold	Standards No. 4
10	262	266	265
15	370	374	381
20	468	465	475
25	555	545	557
30	626	624	632
40	755	764	

My voltage measurements were made with a voltmeter coil and vacuum tube crest voltmeter. I fully agree with the authors that the crest voltmeter is a very satisfactory and convenient instrument for this type of voltage measurement.

P. H. McAuley: (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): The authors have made another contribution to the improvement in sphere-gap calibrations on which a great deal of work has been done in the last few years. It is gratifying to note that their values for the nonirradiated ungrounded gap are mostly within 2 per cent of the present standard values.

In a general way the method of measurements used appears satisfactory when the precautions mentioned in the paper are taken. Much depends on the vacuum-tube crest voltmeter, for which, unfortunately, no details are given. Some Westinghouse testing transformers are equipped with a crest voltmeter operating on the bushing charging current. The same principle was used by Fortescue and Farnsworth in their original fundamental calibration of the sphere gap. It is perhaps appropriate to describe the method briefly at this time.

If Q is the charge of a condenser at a crest voltage E, $2\,Q$ is the change in charge from a voltage $+E$ to $-E$. The change per cycle is $4\,Q$. The average current, disregarding sign, is the charge flowing in coulombs per second. If C is the capacity of the condensers, the average current is $4\,Qf = 4\,CEf$, where f is the frequency. To obtain an indication of the average current, the condenser charging current is rectified and measured with a D'Arsonval type of meter. Either a mechanical or a thermionic type rectifier may be used.

This furnishes a simple and reliable method of measuring high voltages, especially when the testing transformer is equipped with condenser bushings. It is of course customary to check the crest voltmeter against the sphere gap to guard against changes in capacity with voltage. Once its performance is determined, however, it can be relied upon for most testing conditions. It is sensitive to disturbances in the high voltage circuit and, with a thermionic rectifier, trouble may develop in tests causing high frequencies or excessive harmonics. Methods of overcoming these troubles have been described (D. F. Miner, *Electric Journal*, December 1925). An outstanding feature of this crest voltmeter is that it is independent of the load on the testing transformer.

It would be interesting to have the authors report the results of their study of the effect of voltage on the capacities of the bushings. It has been our experience that the effective capacity increases as much as 2 per cent at the higher voltages.

C. S. Sprague and G. Gold: In response to Mr. McAuley's request for more detailed information on the crest voltmeter employed by the authors, the following brief description will be given here.

The working range of the crest voltmeter proper is about 30 volt crest, hence its use on high voltages requires a capacitance divider of known ratio, of which the condenser-type bushing conveniently supplies the high-voltage capacitor. Low alternating voltage up to 30 volts is supplied to the grid circuit of a vacuum tube having a sufficiently high input impedance so as not to disturb the potentiometer ratio. Full-wave rectification of the a-c component is provided by a duodiode in the plate circuit, by which means 2 series condensers, connected as in a voltage-doubler circuit, are each ultimately (after several cycles) charged to a d-c potential proportional to the crest value of the voltage applied to the grids. This d-c potential is in turn applied to the grids of a d-c push-pull amplifier with a milliammeter and a differential shunt in its output circuit, the reading of this milliammeter being a function of the crest voltage of the alternating wave applied to the instrument.

The instrument proper has no inherent calibration but it can be accurately calibrated at low voltage. It is not sensitive to occasional high frequencies but indicates the average value of the applied crest voltage over a number of cycles. Since the indications depend upon the change in plate current, that is, upon the slope of the E_p-I_p curve, and not upon the absolute values of plate current, the instrument is insensitive to changes in the supply voltage.

With proper design, the instrument responds quickly to any change in the applied voltage and is independent of wave shape and sustained harmonics or tooth ripples, even under the most extreme conditions.

When first built the possibility of error due to changes in the characteristics of the vacuum tubes was considered. However, with operation of the vacuum tubes well within their ratings, no trouble of this sort has been experienced in continued operation over periods of a year or more. As with the rectified charging current type of crest voltmeter, the device when used with a capacitance potentiometer can be occasionally checked against a sphere gap. Also with either type of crest voltmeter the capacitance of the condenser-type bushing should be accurately known.

With regard to the change in capacitance of the bushing with voltage the authors are glad to present the following data. The bushings were designed for operation at 300 kv effective. The capacitance was constant up to approximately 55 per cent of this value. Between 55 per cent and 100 per cent the capacitance increased, at first slowly, then more rapidly, ultimately showing a total increase of approximately 1.1 per cent.

Mr. Meador's discussion presents comparative data showing a close check between Mr. Meador's results and those of the authors for nonirradiated spheres. Such a check is always gratifying to both parties.

Basic Impulse Insulation Levels

Closure of a paper by the EEI-NEMA joint committee on system insulation co-ordination, published in the June 1937 issue, pages 711–12, and presented for oral discussion at the insulation co-ordination session of the summer convention, Milwaukee, Wis., June 25, 1937. Previous discussion of this paper appeared in the October 1937 issue, page 1298.

Philip Sporn: Setting up insulation levels on a voltage basis has laid the foundation for carrying on the more important work of the Joint Committee in specifying the insulation strength of all classes of equipment in the established levels and in allocating these levels to the normal system of voltages.

General agreement on the basic levels as indicated in table I, was reached, of course, only after certain compromises and minor differences of opinion. As mentioned by Mr. Foote and as pointed out in the report, consideration should be given to increasing the 100-kv impulse level in the 15-kv class. The apparent lack of agreement here appears to be due to the fact that the 100-kv level really corresponds to the 13.8-kv class (if such were recognized) as can be readily shown by plotting the basic levels against the rated voltage classification. It is planned to give this matter further consideration in the committee.

The heading of column 1 of table I "maximum rated voltage classification" was the heading agreed upon by the committee. As Mr. Foote points out, however, it may be desirable to change this wording if there is confusion, as there apparently is, interpreting the present heading to mean that basic impulse levels are definitely tied up only with system voltages having numerical values given in column 1. A way of clearing up this entire matter might well be by referring to the different basic impulse insulation levels by letters or numbers independent of the system voltage on which they may be applied.

This report covers the progress so far made by the committee in the insulation co-ordination problem. There is still a great deal of work to be done and this may perhaps constitute the major part. If it had been found possible to recount in detail the various discussions within the committee prior to adoption of these levels, a clearer understanding of how the values given in table I were arrived at would be evident. As Mr. Foote points out, "the basic levels are intended to be reference levels." This appears to clearly define what these basic levels are supposed to represent.

Mr. Vogel assumes that these levels are "purely arbitrary since the foundation which is the voltage level which can be maintained by protective equipment is lacking." In other words, a basic level is a benchmark on which all other insulation and protective equipment in the system is based. If I understand Mr. Vogel's comments correctly, he believes that protective devices should be standardized and that transformers and other equipment should be based on the performance of the protective device. Further, if Mr. Vogel's remarks are understood correctly, he would design a piece of apparatus self-protected and place it in a system with the firm belief that the apparatus would perform satisfactorily regardless of whether the system itself functions as a unit or not. This is exactly the type of thing that insulation co-ordination is intended to prevent, that is, the throwing together of a mass of equipment such as power transformers, circuit breakers, instrument transformers, bus insulators, etc., each made to the pet ideas of the individual designer or manufacturer as regards construction and protection without consideration of the broad point of view of the protection of the system as a whole when this equipment is installed and has to work as a unit. Experiencing situations of this kind frequently and in actual practice has been one of the principal factors in giving insulation co-ordination the large amount of attention and consideration that it has been given up to the present time and is still receiving.

It makes little difference where the basic level is set; whether at the protective device, the transformer, the station entrance, or elsewhere, but once set, the problem becomes one of selecting and using margins between the various steps of insulation where these steps are desirable and economically justified. The bases on which these insulation levels were selected were distinctly not arbitrary, but have been co-ordinated so far as information has been available with present-day protective devices. A close study of data published in papers by Messrs. Foote and North and Messrs. Sporn and Gross show clearly that consideration has been given to the protective devices at present available.

As the work of the committee progresses in "carrying out its purpose and scope in:

1. Specification of insulation strengths, and
2. Allocation of insulation levels as mentioned in the paper"

it is believed that the co-ordination of insulation on a power system will become much less difficult. The proper use of the principles of insulation co-ordination will, it is confidently believed, result in more economical power systems.

Insulation Strength of Transformers

Closure of a report of the transformer subcommittee of the AIEE committee on electrical machinery published in the June 1937 issue, pages 749–54, and presented for oral discussion at the insulation co-ordination session of the summer convention, Milwaukee, Wis., June 25, 1937. Previous discussion of this report appeared in the October 1937 issue, pages 1297–8.

L. W. Gross: This paper was intended to give a historical record of the development of the insulation strength of transformers, particularly the impulse strength. In so doing, it was desirable to recount the various steps which were taken in setting up impulse tests on transformers, and in conclusion, the paper gave impulse-test values (tables II and III) of transformer and bushings, together with a brief outline of the proposed method of test where it differed from past procedure.

The fact that a question has arisen since the report was published (as pointed out by Mr. Montsinger) regarding the magnitude of test voltages seems to indicate that perhaps the report was not entirely clear in this respect. It may be well, therefore, to briefly summarize the entire aspect of impulse tests on transformers.

It is recognized that a transformer in service may be subjected to 3 different types of impulses, namely, a full wave, a wave chopped on the tail, and a wave chopped on the front. Impulse testing of transformers has developed today to the point where it is perfectly safe and practical to impose on a transformer in the factory tests with full waves and waves chopped on the tail. Some work has been done and still is in progress on applying tests with waves chopped on the front, that is, front-of-wave tests. The standard wave used to test transformers is the 1½ x 40 wave, and it, of course, may either be of a positive or negative polarity. Since the first of the year when the test procedure was clarified by speaking of impulse-test voltages in terms of their crest value instead of inches of gap—which, of course, was only a test device—the recommended impulse test on transformers boils down to the application of full-wave and chopped-wave applications. Following past procedure, the test now recommended calls for 2 chopped waves but of equal value followed by the full-wave test. The magnitude of impulse-test voltages correspond, in general, to the voltages permitted by the test gaps formerly specified. In accord with action taken by the transformer subcommittee at its meeting in Milwaukee, June 25, it was agreed that the test values indicated in table II of the paper should be recommended, subject to the changes indicated in Mr. Montsinger's discussion above, namely, that distribution transformers in the 15-kv class be subject to a full-wave test of 95 kv and a chopped wave test of 110 kv. Likewise, it was agreed at that meeting to recommend the bushing characteristics given in table III with the change that the 15-kv-class bushing impulse flashover value be changed from 110 kv to 105 kv. These tables II and III with the 3 changes indicated are the latest recommendations of the committee on magnitudes of impulse tests on transformers and their bushings, the sequence of application being 2 chopped waves of equal magnitude followed by one full wave.

While the above 3 changes in voltage values in the 15-kv class from those given in tables II and III have been agreed upon, there is still a feeling by some of the members of the committee that the values should be retained as given in the table. However, since entire agreement could not be obtained it was felt better to go along with the lower tentative values in the 15-kv class than hold up the entire matter until agreement had been reached.

Considerable discussion has developed over the gaps on transformer bushings. Mr. North points out that "gaps mounted directly on bushings are very undesirable and should be discontinued." Others in the industry have voiced the same sentiment, and it seems quite likely that the development of standards for transformers, together with their bushings, will eliminate the bushing gap entirely. It seems perfectly clear that the matter of setting up and testing insulation strength of transformers is one thing and the protection of that transformer is another, whether it be protected by gaps, lightning arresters, or some other device. The 2 problems are, of course, interrelated and should be co-ordinated.

It has been clearly brought out in the discussions that there is a hazard in mounting gaps on bushings due to the possibility, and in many cases almost certainty, that the power arc, which will develop over the surface of the bushing when these gaps break down, will damage the bushing. Actual experience has shown this to be true. It is believed, however, that where gaps are used in connection with transformer protection, they should not be close enough to the bushing to result in a destructive arc on the bushing itself.

Answering Mr. North's question regarding the definition of "a directly grounded circuit," which appeared in the 1930 AIEE Transformer Standards. As near as can be determined at the present time, this definition was set up to accomplish several things;

first, to make it impossible to consider a system's neutral solidly grounded if it had a small grounding bank or potential transformer bank Y-connected with the neutral physically attached to ground. Another point considered appears to have been that the system neutral would be held sufficiently close to ground potential to consider the system grounded if the requirements set up in the footnote were followed. Further, it was considered improbable that troublesome oscillations would be set up in the system due to transient voltages resulting from arcing grounds if the procedure outlined in the footnote were followed in defining the system as directly mounted or isolated.

Application of Arresters and the Selection of Insulation Levels

Authors' closure of a paper by J. H. Foote and J. R. North published in the June 1937 issue, pages 677–82, and presented for oral discussion at the insulation co-ordination session of the summer convention, Milwaukee, Wis., June 25, 1937. Previous discussion of this paper appeared in the October 1937 issue, pages 1293–6.

J. H. Foote and J. R. North: The large amount of constructive discussion of these papers is appreciated and we are especially glad to have the various phases of this matter of insulation co-ordination amplified by others who have been working actively with the problem.

We would like to call attention to 2 corrections which should be made in our paper. On page 680, item (*b*) should not mention fault resistance and should read: "(*b*). The ratio of zero-sequence impedance (including neutral impedance) to positive-sequence impedance...."

The ratio Z_0/Z_1 is indicative to some extent of the effectiveness of the neutral grounding. The voltage during fault conditions from sound phase to ground may range from less than E_n to more than E line-to-line, depending upon the netural conditions. In many cases, it will be found that an 80 per cent arrester may be used if the ratio Z_0/Z_1 is equal to 2 or less and that a 70 per cent arrester may be used if this ratio is equal to one or less; however, it should be distinctly understood that this approximation of the arrester rating is only a general "rule of thumb."

Mr. Halperin has questioned the necessity of the arrester voltage rating being at least 10 per cent above the calculated maximum sound phase voltage-to-ground. The rating of an arrester is based upon the 60-cycle voltage at which it will cut off after discharge. Considering the possibility of a line-to-ground fault coincidental with the surge, it was felt that arresters should have a margin of at least 10 per cent above any such voltage which it might be called upon to clear. The ability of an arrester to clear itself is influenced to some extent by the voltage recovery rate and experience has indicated that the performance is much better on systems having a moderate ratio of reactance to resistance. Then, too, arresters in the lower-voltage classes tend to have a higher factor of safety than those in the higher-voltage classes.

Messrs. Piepho, Ross, and Vogel have inquired as to the characteristics of present day arresters when discharging currents above 5,000 amperes. The value of 5,000 amperes was used in the paper since comparable data regarding the performance of different types of arresters was available at this current value but not generally at the higher values of discharge current. Practically, this is not of great moment since the voltage across the arresters during discharge does not increase lineally with increasing discharging current. The characteristic curve is a logarithmic exponential function and the voltage across one design of arrester during discharge of 20,000 amperes is only approximately 15 per cent higher than that at 5,000 amperes. While arresters of different designs have differing characteristics at high discharge rates, it is generally held that currents much in excess of 5,000 amperes can be discharged before the voltage drop across the arrester reaches the basic impulse insulation level. We are highly sympathetic to the plea for comparable manufacturers' data of arrester performance characteristics at higher values of discharge current and it is to be hoped that this information will be made generally available in the near future. Similar data should also be made generally available regarding the performance characteristics of older designs of arresters and arresters which may have deteriorated in service.

The adequacy of the value of one kv per circuit foot assumed for the short-time potential gradient has been questioned. This value is equivalent to an incoming wave having a front of 1,000 kv per microsecond and without reflection. In particular cases, the assumption of higher values may be necessary but it has generally been felt that one kv per foot represented a reasonably average value considering the actual lengths of circuit feet, circuit connections, and surge conditions as found in practice.

Mr. Sels has discussed the matter of insulation steps and the relative importance of different types of insulation. The relative insulation values of bus insulators, transformer bushings, etc., as given in the figures in the paper, were intended to merely illustrate certain existing insulation levels and were specifically not intended to represent necessary marginal steps between different types of insulation. Fundamentally, it seems to us that there are only 2 major steps of margins required in insulation co-ordination. First, the margin between the performance of the surge protective device under the conditions as assumed and the surge insulation level of the weakest or most important class of equipment; second, the margin between the maximum dynamic voltage-to-ground and the lowest low-frequency flashover or puncture value of insulation under the worst condition of dirt and moisture. Marginal requirements are matters of experience and economics. Transformers have generally been taken as having the limiting minimum insulation strength because of the cost involved and because preferred practice is to place the arresters or other surge protective devices as closely as possible to the transformers. Bushings and insulators have generally been selected with higher impulse insulation strengths because of the relatively small additional cost involved and due to the fact that they are subjected to dirt and moisture and in addition are often located many circuit feet from the protective device.

We fully agree with Mr. Sels that the margins should generally be greater than 10 per cent between the protective device and the apparatus. Furthermore, in our opinion, the margins should properly be expressed in terms of "( ) kv + ( ) per cent" rather than strictly on a percentage basis over the range of voltage characteristics normally considered from the distribution voltage to the highest transmission voltages. It is not apparent that marginal steps are particularly necessary between classes of apparatus in a given basic insulation level except to insure that under the worst conditions assumed for specific classes of apparatus the insulation strength will be in excess of the basic insulation level requirements.

Insulation Co-ordination

Authors' closure of a paper by Philip Sporn and I. W. Gross published in the June 1937 issue, pages 715–20, and presented for oral discussion at the insulation co-ordination session of the summer convention, Milwaukee, Wis., June 25, 1937. Previous discussion of this paper appeared in the October 1937 issue, pages 1296–7.

Philip Sporn and I. W. Gross: It has been some 7 years since the subject of insulation co-ordination has been present in an organized and comprehensive manner and thoroughly discussed, as has been done in this group of papers. The extensive discussions which the papers have brought forth show not only that the subject is very much alive but also give the electrical industry an opportunity to observe what has been done during recent years in the development of thinking on co-ordination, the thoughts behind the development, and the progress made in its application.

The question of establishing margins between different types of apparatus, to obtain co-ordination, is an important one and has been discussed from several points of view. It is particularly interesting to know what some of the operating companies are doing in arriving at these margins. Mr. Sels, for example, is allowing 30 per cent margin between lightning arresters and transformers as he feels that margins of 10 per cent are not adequate. Mr. Foote's analysis of margins between arresters and transformers is extremely interesting as it brings out some of the variables which have to be considered in arriving at and recommending insulation margins. The practice of Mr. Sels' company in making the transformer the strongest piece of equipment in the station, with the bus itself graded lower, is, as pointed out, exactly opposite to that of our company. Situations of this kind show clearly the need for establishing classes of insulation levels so that they may be adapted to the individual needs and practices of the various users. Certainly at the present time no one can say that either one of these practices is right and the other wrong; and for the conditions met within service it may be that each of these practices, although exactly opposite in principle, is economically sound in application.

Mr. Vogel has mentioned the self-protected transformer in the distribution-voltage class where protective devices are built into the transformer itself. This, of course, is similar to the practice of some companies today in locating lightning arresters directly on the transformer tank, a practice which we started as early as 1928. The question immediately arises, therefore, if distribution transformers are to be equipped with protective devices, why should not power transformers also be so equipped? This would mean that power transformers might be supplied complete with lightning arresters attached thereto, as standard equipment.

In connection with the impulse testing of transformers it has been our practice in recent years to not only equip power transformers with lightning arresters placed directly on the transformer make but also to impulse test practically all of these larger transformers. In addition to the standard impulse tests which have been developed during the past few years we require an additional impulse test on the entire unit including the arrester. That is, an impulse is applied to the transformer with the lightning arrester connected to it. The purpose of such a test is to observe the voltage characteristics permitted on the transformer by the lightning arresters under conditions simulating as nearly as possible actual field conditions. Impulse test voltages which would rise to something in the order of 3 times the magnitude permitted by the transformer test code, if the arrester were not present, have been applied to transformers in combination with arresters, the rate of voltage rise in some cases being considerably in excess of 1,000 kv per microsecond.

In addition to testing the impulse strength of the transformer itself under commercial conditions we are strongly in favor of this practice in applying a severe impulse to the transformer equipped with a lightning arrester as the installation will actually be made in the field. We would suggest that some thought be given in our technical committees in setting up the standard procedure for applying impulse tests to transformers equipped with lightning arresters.

A great deal of the discussion has apparently centered around the possibility of obtaining 100 per cent protection against impulses. We wish to refer again to that part of our paper which states the problem of "insulation co-ordination" centers around economy. This means that working out the problem of protecting equipment, while technically we may be able to protect apparatus practically 100 per cent against breakdown from impulse, it may not be the economical thing to do, and therefore we face the possibility of an occasional failure under severe impulse conditions rather than build into the apparatus itself insulation strength and into the protective device sufficient protection to eliminate failure for almost any conceivable type of impulse.

It is believed that, with the work which has already been done, and the field experience which is now being accumulated, we are fast collecting a store of information which will make this insulation co-ordination problem much simpler to handle in the future, giving us a set-up finally where it will be possible to predict the operating results of applying these principles with a considerable degree of accuracy.

Application of Spill Gaps and Selection of Insulation Levels

Authors' closure of a paper by H. L. Melvin and R. E. Pierce published in the June 1937 issue, pages 689–94, and presented for oral discussion at the insulation co-ordination session of the summer convention, Milwaukee, Wis., June 25, 1937. Previous discussion of this paper appeared in the October 1937 issue, pages 1290–3.

H. L. Melvin and R. E. Pierce: In the discussion by Messrs. Foote and North the criticism as to the use of the term "level" as being applicable to a spill gap is well taken. It is perhaps unfortunate that the term "insulation levels" was ever applied to gaps and insulators in view of the many later attempts to picture these insulation levels as fixed or uniform values of voltage regardless of time. The origin of the term was of course closely associated with the idea of defining insulation levels in terms of "inches of rod gap."

The authors believe that the experience cited justifies the first conclusion in the paper, namely, that "spill gaps are effective as a means of establishing and co-ordinating insulation levels on lines and stations, and affording dependable protection to equipment and insulation, against failure from lightning." It is of course brought out in the paper that spill gap settings and equipment insulation strengths must be properly co-ordinated. Also instances are cited where spill gaps were set too wide to protect equipment probably in the short time zone.

The wide range of gap settings used for the same operating voltage in different locations is more the result of different methods and stages of experimentation with gap settings under service conditions rather than of calculations or complete tests to determine minimum practicable gap settings. It is therefore, doubtful if detailed explanatory data on such items as insulation strengths of apparatus and system sequence impedances would be pertinent for most of the situations cited. For the one 110-kv substation in Louisiana, however, where definite and more complete tests were carried out to determine the minimum gap settings permissible, the 110-kv system neutral is effectively grounded and the ratio of zero-sequence impedance to positive-sequence impedance is in the order of from 0.7 to 1.0 under most operating conditions. Experience has shown that designers' estimates of the impulse insulation strength of specific transformer units have been gradually lowered over a period of years as additional failures have occurred and more has been learned regarding the co-ordination of the design of the complicated insulation structure within a transformer.

Westinghouse Photo

The experience of the South Texas Company with the use of fused spill gaps as described by Mr. M. H. Lovelady is of decided interest and is further confirmation of the authors' second conclusion, namely, that minimum permissible spill gap settings are less than those previously considered possible.

With reference to table I in the paper, showing the operating record of spill gaps in Texas, it is understood that the only means used to determine whether or not these gaps operated was by periodic visual inspection.

Mr. Rorden raised the question as to whether experience indicates that most insulation failures are associated with a single severe surge, such as a direct stroke, or if there are a fair percentage of failures that occur with strokes of lesser magnitude and current, such as traveling waves, also Mr. Ross inquires if experience indicates the relative destructive effect of switching surges, induced surges, and direct strokes. The authors believe experience has fairly definitely shown that direct strokes are the only real concern as far as destruction of equipment from impulse voltages is concerned, and that the destructive effect of switching surges and induced surges are fully guarded against if the design of equipment and its protection from direct strokes is adequate. However, there are so few instances of insulation failures in which all of the facts are known that it is probably more a matter of opinion that most insulation failures are associated with a single severe direct stroke nearby, rather than from direct strokes to the line at some distance, which appear at the substation as traveling waves.

Answering the other question by Mr. Ross, the authors have no definite test data relative to the wave shape of switching surges. However, it is also our opinion that many, if not all, switching surges have characteristics intermediate between 60-cycle voltages and relatively slow rate of rise impulse voltages.

Answering the questions raised by Mr. McEachron, the fused gaps used on the 110-kv system discussed on page 691 were rated 8 amperes. The repeater type fuse operates in from 15 to 30 cycles. There are, of course, plain back-up rod gaps used in connection with all of the repeater fused gaps, having slightly higher settings, which prevent loss of protection during the interval required for the repeater fuses to come into position. Where permanent installations are made of several fused gaps in multiple, the loss of even the difference in degree of protection between the fused and back-up gaps is prevented until all fuses have operated.

News
Of Institute and Related Activities

Important Developments in Publication Policy Announced

By I. Melville Stein, Chairman AIEE Publication Committee

TO MEET the definitely expressed wishes of the Institute's membership for a broader publication service, the AIEE publication committee has been studying publication policies during the past year or so.

An initial step in this direction was taken, upon the committee's recommendation, in January of this year when the board of directors approved an additional appropriation for the publication in ELECTRICAL ENGINEERING of more articles of broad general interest during the remainder of the appropriation year ending September 30, 1937. Since that time, the publication committee has continued its study of publication and related policies with a view toward improving still further the value of the Institute's publications to the membership. To assist the committee in better determining and meeting the wishes of the membership, the subject was discussed at some length at the conference of officers, delegates, and members held during the Institute's 1937 summer convention in Milwaukee, Wis. The AIEE technical program committee also has studied the situation as it affects the work of that committee, and has made certain recommendations.

As an outgrowth of these various deliberations the publication committee has completed plans for some important developments in publication policy and procedure, which were approved by the board of directors at its meeting on October 28, 1937. These developments are outlined in the following paragraphs.

The policy of including in each issue of ELECTRICAL ENGINEERING a substantial number of articles of broad general interest will be continued, and it is expected that the changes in policy just adopted will make possible an appreciable improvement in this section.

Advance copies of all papers approved by the technical program committee for national conventions and District meetings will be provided for the use of the technical program committee and the convenience of others interested. These advance copies will be in the form of reproduced manuscripts of accepted papers, these manuscripts being subject to revision before final printing. They will be available at headquarters or at the registration desk at meetings or conventions at a price of 5¢ each; by mail the price will be 10¢ each. ELECTRICAL ENGINEERING regularly will carry announcements of advance copies as they become available.

Technical program papers will be published in a segregated section of ELECTRICAL ENGINEERING after they have been presented and finally reviewed (instead of before presentation as at present), so that the approved discussions can be correlated and published with their respective papers. Some highly technical papers that are considered to be of limited interest will be abstracted in ELECTRICAL ENGINEERING and will not appear there in full. (Such papers will be published in full in the TRANSACTIONS.) For the present it is contemplated that approximately two-thirds of the regularly approved technical program papers will be published in full in this segregated section of ELECTRICAL ENGINEERING.

The TRANSACTIONS will include only finally reviewed papers and correlated discussions approved by the technical program committee, but all formal papers presented on the technical programs at national meetings and those approved by the technical program committee for presentation at District meetings will be included except in rare special cases.

The publication committee believes that these modifications in policy and procedure should result in an improved publication service to the membership, and in a reduction of the time elapsing between the submission of a technical paper manuscript and its presentation at a national convention or District meeting. The new policy will be made effective with the January 1938 issue of ELECTRICAL ENGINEERING.

Comments and criticisms will be sincerely appreciated by the publication committee.

1938 International Management Congress

The Seventh International Management Congress will be held at Washington, D. C., September 19 to 23, 1938, under the auspices of the International Committee of Scientific Management (CIOS), of which Lord Leverhulme of Great Britain is president. Authorities on industrial and commercial management from about 40 countries are expected to attend. An American Congress Council has been formed with Willis H. Booth, honorary president of the International Chamber of Commerce, as chairman, to sponsor the gathering.

Discussions of the latest developments in management and the social and economic aspects of management, based upon more than 200 papers selected competitively from experts all over the world, will comprise the congress. Six sections, convening simultaneously, will deal with management problems in production, administration, distribution, personnel or labor relations, agriculture, and the home. Leaders in business are expected to take part in the discussions, together with invited governmental representatives. Extensive tours for foreign visitors through the plants and offices of industrial and commercial establishments, noted for their application of scientific management, are planned.

The congress will be under the direction of the National Management Council of the United States of America, affiliate of the international committee. It is composed of the following organizations: American Management Association, The American Society of Mechanical Engineers, The Association of Consulting Management Engineers, International City Managers Association, Life Office Management Association, National Office Management Association, Personnel Research Federation, and Society for the Advancement of Management. A co-ordinating committee, of which W. L. Batt, president of SKF Industries, Inc., and past-president of ASME, is chairman, has been formed with the following officers: *vice-chairmen*—Harry Arthur Hopf, William H. Gesell, Thomas R. Jones, Henry P. Kendall; *treasurer*—Charles G. Smith; *general secretary*—John J. Furia. Sectional chairmen include James O. McKinsey, for administration, Ralph E. Flanders for production, Leon C. Stowell for distribution, W. W. Kincaid for agriculture, and Marie M. Meloney for the home. American Engineering Council's executive committee, on the request of the co-ordinating committee, has authorized the secretary of AEC, F. M. Feiker (M'34), to serve as Washington secretary of the congress.

Previous congresses have been held at Prague (1924), Brussels (1925), Rome (1927), Paris (1929), Amsterdam (1932), and London (1935).

New NEMA Bulletins. The National Electrical Manufacturers Association has issued 2 new publications: (1) INDUSTRIAL CONTROL STANDARDS, publication number 37-44; and (2) INSTRUCTIONS FOR CARE AND OPERATION OF TRANSFORMERS, publication number 37-46. The first bulletin is a revision of a previous publication on the same subject, and the second contains instructions for the care of both distribution and power transformers. Copies of these pamphlets may be obtained from the headquarters of the National Electrical Manufacturers Association, 155 East 44th Street, New York, N. Y.

Industrial and Other Topics Feature Busy Sessions at Akron—Students Take Active Part

SUPPORTED by an unusual variety of inspection trips to many different types of industrial plants, there was a very effective industrial flavor to the general meeting of the AIEE Middle Eastern District held in Akron, Ohio, October 13–15, inclusive. About a third of the 23 papers on the program dealt with problems of an industrial nature in which electrical engineers are directly interested through the development, application, or operation of a wide variety of machinery and control equipment. Also afforded a place on the program were timely papers and discussions concerning such topics as radio interference, transportation, electrical machinery, electronics, and power transmission.

This was the ninth District meeting to be held by the Middle Eastern District, and the first since 1932. Other meetings that have been held by the District are (attendance indicated in parentheses): Washington, D. C., January 1925 (212); Cleveland, O., March 1926 (430); Bethlehem, Pa., April 1927 (400); Baltimore, Md., April 1928 (400); Cincinnati, O., March 1929 (270); Philadelphia, Pa., October 1930 (500); Pittsburgh, Pa., April 1931 (500); Baltimore, Md., October 1932 (240).

Chairman A. O. Austin of the Akron Section opened the initial session, introducing Mayor Lee D. Schroy who welcomed the visitors and outlined some of the local features that he deemed to be of interest to engineers. In responding to Mayor Schroy Vice-President I. Melville Stein cited the fact that 3 of the renowned pioneers in the electrical industry were born in Ohio: Theodore N. Vail, Thomas A. Edison, and Charles F. Brush.

Presiding at the various technical sessions were: I. Melville Stein, vice-president from District 2 and past chairman (1927–28) of the Philadelphia Section; Russell Krammes, past-chairman (1931–32) of the Akron Section; A. M. MacCutcheon, past-chairman of the Cleveland Section (1920–21), one time director (1928–32), and past-president (1936–37); J. R. Martin, Cleveland; G. R. Fink, Philadelphia; F. W. Funk, Akron.

Doctor W. E. Wickenden, president of Case School of Applied Science, and past-chairman (1936–37) of the Cleveland Section presided and acted as toastmaster at the concluding banquet, where President W. H. Harrison spoke briefly prior to the introduction of the guest speaker, Commander C. E. Rosendahl. To Harold L. Brouse (A'32) electrical engineer, B. F. Goodrich Company, and chairman of the general committee for the Akron meeting, special tribute was paid by Toastmaster Wickenden and all those assembled. Confined for some time by illness, Mr. Brouse was a listener-in on the program through the medium of a microphone pick-up and a special direct wire. R. A. Hudson (A'30) efficiency engineer with Goodyear Tire and Rubber Company, was credited with effective "pinch-hitting" for Mr. Brouse.

Analysis of Registration at Akron Meeting

	Location			
Classification	Akron	District No. 2*	Other Districts	Totals
Members........	30 ..	165 ..	35 ...	230
Students.........	6 ..	125 ..	1 ...	132
Men Guests.....	7 ..	40 ..	7 ...	54
Women Guests	12 ..	32 ..	4 ...	48
Totals..........	55 ..	362 ..	47 ...	464

* Outside of Akron Section

Radio Interference

On the increasingly important subject of radio interference, one formal published paper and 2 informal papers prepared especially for the Akron meeting were presented and actively discussed:

A Review of Radio Interference Investigation, Frank Sanford (A'28, M'34) and Willard Weise; both are employed by the Cincinnati Gas and Electric Company (published, October issue pages 1248–52).

Notes on Radio Interference, Grover Lapp (A'22), chief engineer for the Lapp Insulator Company, Inc., LeRoy, N. Y. (not published).

Radio Disturbance Measurements, W. S. Jennens and C. J. Miller, Jr., Barberton, Ohio, electrical engineers; both are employed in the Ohio Insulator Company Division of the Ohio Brass Company (not published).

Brief review of the subject was given by Messrs. Sanford and Weise who described radio interference elimination as "essentially the co-ordination of this use of electricity with its other uses for light, heat, power, and transportation, in order that the growth of each may not be restricted by the requirements of the other," and who consider as practical an approach to the problem similar to the effective approach to the problem of inductive co-ordination with reference to wire communication. Effective co-operative control measures experimentally developed in Cincinnati were briefly described.

G. W. Lapp analyzed conditions contributing to radio interference, with particular reference to transmission line insulators, and to the various methods now being followed on modern power systems for control or elimination. He pointed out that at least one by-product of interference control that is of direct value to the operating utility has been the discovery and elimination of points of incipient failure. In discussing radio characteristics of insulators he stressed the continuing importance of field tests to supplement laboratory tests and developments, considering the variation in contamination of atmosphere in different localities. He emphasized the fact that "considerable information is now available from actual cases, so that insulators can be specified with confidence to meet unusual types of severe conditions," and concluded that "the problems of satisfactory freedom from radio interference on insulators have been met as the needs have appeared and in such a way that future demands can be taken care of as they arrive."

Messrs. Jennens and Miller called attention to the method outlined by the National Electrical Manufacturers' Association for measuring radio interference on high-voltage insulators, describing it as "probably the most satisfactory method now available for laboratory use"; they stated—that this method "probably will be used by most of the insulator manufacturers, and eventually radio interference data will be correlated between the various laboratories." They pointed out, however, that before the NEMA method can be used to determine radio interference, it is necessary to correlate the microvolts across the insulator as measured by the NEMA method with the field strength of radio interference that the insulator will create when used on a transmission line. They gave various correlation data and described testing equipment and methods used.

Mine Ventilation

"Improvements in Mine Ventilation" were described by Doctor Theodore Troller of the Guggenheim Airship Institute. As indicative of the train of beneficial development resulting from well-organized basic research, Doctor Troller described several noteworthy advances in equipment and technique of mine ventilation that have grown directly from the fruits of research originally directed toward aeronautical problems.

Doctor Troller outlined briefly the peculiar requirements of mine ventilation, citing it as typical relatively low-pressure high-quantity (20,000 to 300,000 cubic feet per minute) service, and one where notable improvements in fans have been made and more may be expected. He cited the case of one coal company where the electric power bill for mine ventilation amounts to as much as $150,000 per year, pointing out that in such a case each one per cent improvement in the efficiency of fan or related electrical equipment meant a reduction of $1,500 per year in the ventilation power bill. He reported the modern trend toward the use of propeller type fans because of their adaptability to the peculiar and varying requirements of mine ventilation, stating that "maximum efficiencies of 80 to 85 per cent can be combined with a power characteristic having the maximum power required at or near the point of maximum efficiency." He stated further that "in a few years the propeller type fan should be developed from the laboratory state to practical installation so that 90 per cent efficiency will be a regular feature, and its weight and size further reduced by about 30 per cent."

Industrial Switchgear

"The Advance in Industrial Switchgear" was treated at some length by V. L. Cox

(A'28) of the switchgear division, General Electric Company, Philadelphia, Pa., emphasizing the necessity for continuing advance in the development of switchgear to meet the ever more complex and rigorous requirements of modern industry. Mr. Cox traced the steps followed in laying out electrical equipment for the modern plant. He described and illustrated numerous varieties of factory-built and assembled equipment which in many cases includes the complete complement of related auxiliary, control, and metering devices.

RUBBER INDUSTRY

The rubber industry came in for its share of consideration in 2 papers; the first was "Electrical Applications in Rubber Mills," by John Grotzinger (A'24), chief electrical engineer, and R. S. Ferguson and W. A. Brown of the Goodyear Tire and Rubber Company, Akron. Mr. Grotzinger and his co-authors presented a general outline of the major processes of a manufacturing plant producing rubber tires and tubes, and described the more important items of equipment used. They listed the principal power requirements for a typical plant and described methods of pre-determining energy requirements and maximum demands for plants of any capacity. Opportunities for generating power from process steam were briefly reviewed, and evidence furnished indicated that fully 50 per cent of energy requirements could be met in such a manner. (Figures given indicated a power requirement of about 0.55 kva per tire for plants capable of producing 10,000 or more tires per day, whereas a plant having a capacity of 300 tires would require about 2.2 kva per tire.)

"Recent Developments of Electrical Equipment for the Rubber Industry" were discussed by C. W. Drake (M'21) industrial sales engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. Supplementing the previously mentioned paper which covered the matter of applications, Mr. Drake discussed the engineering and related problems involved in the development of electrical equipment to meet the peculiar requirements of the rubber industry.

In this discussion Mr. Drake covered 2-speed motors for Banbury mixers, and dynamic-braking starters for synchronous-motor mill-line drive. The motors discussed were synchronous machines rated at 600–1,200 or 450–900 rpm, and they were discussed in connection with various related control and protective equipment. Under the subject of dynamic-braking starters, he described and illustrated new assemblies or arrangements of equipment intended to be "of special value in connection with the present trend toward enclosed or cubicle-type equipment and the mounting of such control in remote locations," covering recent developments of several combinations of electrically operated circuit breakers "to provide forward and reverse operation with dynamic braking, performing the same functions as older types of control, but having numerous advantages from the standpoint of installation, maintenance, and especially compactness."

Future AIEE Meetings

Winter Convention
New York, N. Y., January 24–28, 1938

North Eastern District Meeting
Pittsfield, Mass., Spring 1938

Summer Convention
Washington, D. C., June 20–24, 1938

Pacific Coast Convention
Portland, Ore., date to be determined

Southern District Meeting
Miami, Fla., Fall 1938

IRON AND STEEL INDUSTRY

An insight into some of the electrical and related problems in the many ramifications of the iron and steel industry was given through the medium of 3 descriptive papers, all of which were published in the September issue:

SOME HIGH LIGHTS IN THE USE OF ELECTRICITY IN STEEL MILLS, E. G. Fox (M'20), Freyn Engineering Company, Chicago, Ill.

CARBON BRUSHES FOR STEEL MILL EQUIPMENT, W. C. Kalb (M'15), advertising department, carbon sales division, National Carbon Company, Cleveland, Ohio.

TENSION MEASUREMENT AND CONTROL IN COLD STRIP ROLLING, C. M. Hathaway (A'29), and F. Mohler, mechanical engineers, general engineering laboratory, General Electric Company, Schenectady, N. Y.

In addition to describing some of the more interesting features of steel mill electrification, Mr. Fox pointed out that approximately one-tenth of the investment in the American steel industry is in electric plants, and that the power consumption of steel mills is increasing; that about two-thirds of this power is generated within the plants, but that there is a tendency toward an increased purchase of power. He mentioned also that electric melting furnaces supply a small but growing increment of total steel production; that high-frequency heating is finding some uses; that new types of electric furnaces are being installed for heat treating and annealing operations.

Messrs. Hathaway and Mohler described a device called a "tensiometer" designed for the measurement of the tension in steel strips during rolling in a cold-rolling mill, and for the indication of any difference in tension between the 2 edges of the strip. They reported that "the tensiometer can function in connection with auxiliary control equipment for the automatic maintenance of the total tension to any desired value."

Mr. Kalb discussed problems associated with brush application on commutating types of equipment in the iron and steel industry, in relation to type of equipment and conditions encountered in service; discussed also a newly defined measure of brush performance, termed "commutation factor" which "provides an improved basis for control of the performance characteristics of brushes." He mentioned also the development of electrographitic grades designed to prevent the formation of troublesome surface film on commutators exposed to the contaminating atmospheric conditions frequently encountered in steel-mill applications.

STEAM TURBINES

"Some Recent Applications of Steam Turbines in Industrial Plants Showing Upward Trend in Pressures and Temperatures" were described by K. S. Kramer of the South Philadelphia Works of the Westinghouse Electric and Manufacturing Company. Concerned primarily with problems incident to industrial plants where the requirements of steam for processing purposes are of prime importance, Mr. Kramer described typical installations, pointing out that the wide diversity in requirements for process steam had led turbine manufacturers for the past 10 or 15 years to build industrial turbines to special order. He reported that both condensing and noncondensing turbines have "been built for extraction of steam nonautomatically at one or more pressures, and automatically at one or two pressures in addition to nonautomatic extraction. Turbines have been built for induction as well as extraction of steam and, in some cases, extraction at one pressure and induction at another. Inlet pressures may be as low as several pounds; in some instances turbines were supplied with inlet steam at 2 pressures. Most turbines can be designed for initial operation with low pressures and temperatures, and later by minor changes made suitable for efficient operation with much higher pressures and temperatures."

RAILWAY ELECTRIFICATION

Two different problems incident to railway electrification were covered in papers presented:

THE DESIGN AND TEST OF A HIGH-SPEED HIGH-INTERRUPTING - CAPACITY RAILWAY CIRCUIT BREAKER, W. F. Skeats (M'36), and H. E. Strang (A'28), both of the General Electric Company, Philadelphia, Pa.

PENNSYLVANIA RAILROAD ELECTRIFICATION, H. C. Griffith (M'35), electrical engineer, Pennsylvania Railroad Company, Philadelphia, Pa.

Mr. Skeats described and illustrated a circuit breaker designed for 25-cycle 1,500-ampere 15-kv normal service and capable of interrupting a fault current of 65,000 amperes with an over-all short-circuit duration of one cycle. He reported that "being intended for railway trolley service, which is rather severe from the standpoint of frequency of short-circuit operation, it is expected to handle 50 short-circuit operations without internal inspection or change of oil...this breaker operates upon the impulse principle." A spring-driven system forces a blast of oil through a special passageway which causes the oil to sweep directly across the arc path, a departure in design from the earlier breakers which used a "radial" blast of oil. Mr. Skeats described test methods and results.

Mr. Griffith described the scope and character of the main-line electrification project now being actively prosecuted by the Pennsylvania Railroad. Electrified lines now in operation, including the trackage used for suburban service, covers 373 miles of line, involving 1,343 miles of electrified track between New York and Washington, and from Philadelphia to Paoli, Pa., on the main line west. The project now under way will complete the main-line electrification from Paoli through Lancaster to Harrisburg for passenger service, and various main freight lines east of Harrisburg. This new work will add to the Pennsylvania system some 315 miles of electrified line involving some 773 miles of track. Mr. Griffith reported that "upon completion of the new work, the Pennsylvania Railroad system will have a total of 2,677 miles of electrified track, or 41 per cent of the total electrically operated standard railroad trackage in the entire United States."

ELECTRICAL MACHINERY

"Single-Phase Induction-Motor Performance" was discussed in mathematical terms by A. F. Puchstein (A'20, M'27) and T. C. Lloyd (A'31) respectively chief engineer and development engineer, Robbins and Myers, Inc., Springfield, Ohio. This paper was published in full in the October issue. In discussing their subject at Akron, the authors reported: "In a search for labor saving methods for predicting the pull-out torque (or its equivalent, the number of primary-winding turns) and the performance curves of the single-phase induction motor from design-sheet data with satisfactory precision, it became necessary to examine as much of the existing literature as could be found" (the work of 25 or more writers on the subject since 1895), and stated that "the present paper was an attempt to reduce greatly the labor of numerical application, while maintaining the accuracy within the limits dictated by modern practice."

"Recent Trends in the Design of Power Transformers" were described and illustrated in some detail by L. H. Hill (A'22, M'29) engineer-in-charge, transformer division, Allis-Chalmers Manufacturing Company, Milwaukee, Wis. Mr. Hill stated that "during the past 15 years . . . there have been more changes in power transformer design than in all the years prior to that time." He called attention to such modern trends as improved internal mechanical construction, designing for impulse strength and the related tendency to use dielectric flux control to reduce internal oscillation, and reported a trend toward "increased use of tap changing under load both in straight transformers and in regulating units, increased use of phase-angle control under load, forced-air-blast equipment, inert-gas protection, design for oiltightness, use of large 3-phase units, and multiwinding units."

ELECTRONICS

"Low-Current Ignitors" were described by A. H. Toepfer (A'31) research engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. He outlined briefly the various developments that have grown from the initial work of Slepian and Ludwig incident to the design and operation of the so-called ignitron tube, devoting principal attention to the problem of proper materials and design of the ignitor tip. This paper was published in full in the July issue.

The "Regulation of Grid-Controlled Rectifiers" was discussed at some length by L. A. Kilgore (A'29) and J. H. Cox (A'25) respectively design engineer and section engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. They reported that "this paper discusses several factors which have not been included in the previously published regulation formulas and which should be considered in the practical application of rectifiers. Approximate solutions are given to take into account system reactance and the load inductance." Consideration also is given to the effect of grid pick-up characteristics on regulation, and means of modifying the inherent regulation characteristics by regulators or compensators. This paper was published in full in the September issue.

In discussing "The Igniter-Type Mercury Arc Rectifier as a Power-Conversion Unit," A. Lee Barrett, Pittsburgh Coal Company, Pittsburgh, Pa., reviewed briefly the changes since 1930 in coal-mining operations which have changed materially the problems of electric power supply. Strong tendencies toward mechanization, toward concentration of actual mining operations in smaller areas within a given mine, and toward multiple-shift operations have had at least 2 important effects upon requirements for electric supply: first, increasing the electric load at the working faces from the earlier total of about 25 per cent of the total mine load to the present figure of from 50 to 60 per cent of the total mine load; second, requiring more frequent relocation of underground substations. He reported some economic and mechanical details incident to recent and projected installations of underground rectifier substations of the igniter or multiple-tank type, stating that these "would seem to provide the mining industry with a substation no more expensive than contemporary substations. . . much more portable . . . efficiency is substantially better than anything heretofore available."

The use of "Mercury Arc Rectifiers in Chlorine Production" was described and explained by L. J. Rimlinger, chief electrical engineer, Columbia Chemical Company, Barberton, O. Mr. Rimlinger described a 7,000-kw 500-volt d-c rectifier installation recently placed in operation involving 2 2,000-kw 12-anode double-6-phase units each connected to an individual supply transformer, and one 3,000-kw unit involving 2 tanks operating on one transformer, 12 anodes each, and double-6-phase. To meet the requirements of electrochemical service he explained that "mercury arc rectifiers were selected for converting equipment because of their low operating cost, high efficiency, and their suitability in corrosive atmosphere."

LIGHTNING VERSUS POWER TRANSMISSION

Lightning still is given a prominent position in discussions pertaining to electric power transmission. Three of the Akron papers dealt directly with this subject.

"Lightning-Proof Transmission Lines" of the Pennsylvania Water and Power Company were described by Edwin Hansson (A'19, M'35) and A. F. Bang (A'11) respectively transmission engineer and superintendent of operation for that company. The method of lightning protection described "consists of the proper combination of overhead ground wires, low tower-footing resistances obtained by means of a counterpoise, and ample insulation. Its successful application is illustrated by operating records . . . Performance of any given line can be predicted if the tower-footing resistances are known." Theory of protection outlines: "(1) that overhead ground wires must be placed so as to shield the conductors completely from direct strokes, thus eliminating flashovers from conductor to tower; (2) that the ground wires and towers must be so connected to earth that the current from the lightning stroke will be drained off without raising the potential of the structure to a value which will cause a flash from tower to conductor." Results cited: (1) 5 years operation of a 92-mile single-circuit 230-kv line with one lightning operation; (2) 3 years' operation of a 4-circuit 32-mile 132-kv line with no lightning operation; (3) $1^{1}/_{4}$ years' operation of a 2-circuit 23-mile 69-kv line with no lightning operation; "all lines located in severe lightning territory . . . average storms per year respectively, 62, 42, 39." This paper was closely related to a paper by S. K. Waldorf (A'27, M'36) test engineer of the same company, "Probable Outages of Shielded Transmission Lines," published in the May 1937 issue.

In discussing "Lightning Strokes in Field and Laboratory," P. L. Bellaschi (A'29, M'34) section engineer in charge of transformer engineering, Westinghouse Electric and Manufacturing Company, Sharon, Pa., concerned himself principally with the fundamental aspects of the problem, particularly with the characteristics of the lightning-stroke channel. He gave data and findings revealing further the nature of the channel core and of the resulting column, and submitted field observations for comparison purposes. This paper was published in full in the October issue.

"Cross-Catenary Transmission Lines for Lightning and Fog Conditions" were described by A. O. Austin (A'04, F'25) consulting and manufacturing engineer, Barberton, Ohio. Mr. Austin discussed 2 methods of achieving electrical reliability against lightning interruption: "In one method the ratio of the arcing voltage to the impedance in the lightning-diverting path constitutes the index of reliability where the line is equipped with ground wires. In the second case the high arcing voltage together with the limitation of current due to high ground resistance or other means produces a high resistance in the path to ground and prevents the follow-up of normal-frequency current." He further states that: "The ease of obtaining a high arcing voltage to ground with the cross-catenary type of construction makes it possible to develop either type to its maximum. The very high arcing voltage to ground with limited insulation between phases results in smaller structures and lower cost for a given standard. The double insulation in the cross-catenary construction provides a high degree of reliability not possible with single insulation. . . . The relative advantage is appreciable at lower voltages, but increases materially with the voltage. Clearance between phases or between conductors and ground which would be prohibitive with the usual types of construction can readily be obtained with the cross-catenary type. The development of low-capacitance high-voltage radio strain insulators removes the previous electrical and mechanical limitations of insulation for the cross span." Mr. Austin cited the "wide use of guyed cross-catenary construction for the Penn-

Membership—

Mr. Institute Member:

The coming winter activities in national, District, and local groups will provide you with a strong appeal to your fellow workers when you speak to them about AIEE membership. An invitation to participate with you in these meetings and other affairs, when permissible, should prove helpful in creating a better understanding of Institute aims and activities. If one or more of your associates should indicate an interest in joining, and if you feel he or they would make desirable members, please let your membership committeeman know about it.

C. M. Foust

Vice-Chairman, District No. 1
National Membership Committee

sylvania Railroad for its recent electrification" as showing "a growing trend toward the use of the cross-catenary construction."

D-C Transmission

"Possibilities of Direct-Current Power Transmission Using Electrically Controlled Rectifiers and Inverters," were discussed by O. K. Marti (A'21, M'27), engineer in charge of rectifiers and railway equipment, Allis-Chalmers Manufacturing Company, Milwaukee, Wis. He outlined some of the problems of power system stability; he stated that "from preliminary considerations it would appear that these difficulties in transmitting power would be overcome if direct current were used, and it therefore seems justifiable to look carefully into the possibility of transmitting power by means of direct current. This is particularly true since it appears to be possible by means of the latest development of the grid-controlled electric power valve to convert a-c power to d-c at high-voltage, for d-c transmission, and invert the d-c power back into a-c of any desired frequency and voltage, without great cost and with little loss of power." He reported briefly the high lights of 30 years of operating experience with the 275-mile 125-kv d-c transmission system between Mougiers and Lyon, France, in connection with which were put into practical application the original development of Rene Thury, the Swiss consulting engineer, who is generally regarded as the father of d-c high-voltage transmission.

Mr. Marti stated that "it seems now that the argument between the proponents of direct and alternating currents will again be revived. The principal reason for this is the fact that the electronic power valve has reached a stage of development where it can be employed without difficulty to handle the high voltages and currents coming into consideration for the commercial transmission of electric power."

Student Program

More than 130 electrical-engineering students—nearly a third of all those attending the Akron meeting—contributed to the effectiveness of the general program and themselves held a technical session that drew not only full attendance from their own group, but also a good many practicing engineers from the general session that was held in parallel. General arrangements for the students' participation in the program were under the direction of J. T. Walther (A'19, M'26) professor of electrical engineering, and counselor of the Student Branch at the University of Akron, and past-chairman (1924–25) of the Akron Section.

The 6 papers presented on the student technical session program were as follows:

Measurement of Reverberation Time with the Cathode-Ray Oscillograph, H. W. Lensner, Case School of Applied Science.

We, the Students, Nelson A. Powell, Ohio University.

Pressure Insulated Conductor for High-Voltage Transmission, J. B. Adams, Jr., Johns Hopkins University.

The Telephone Inverter, Frank Andrix, Ohio State University.

An Engineer's Training, A. H. Graham, West Virginia University.

Saturable Core Reactor, Robert F. Miller, University of Akron.

Subsequent to the technical session, the chairmen and the student counselors of the various Student Branches in the Middle Eastern District gathered in separate groups for conferences and an exchange of ideas concerning the effective conduct of Student Branch activities. Following these conference group meetings, a general luncheon of the 2 groups was held, supplemented by others interested in student affairs including President W. H. Harrison, National Secretary H. H. Henline, Past-President A. M. MacCutcheon, Past-Chairman O. W. Eshbach of the AIEE committee on education, and Editor G. R. Henninger. Actions reported at this meeting included:

1. Decision to hold 1938 student conference at Bucknell University, Lewisburg, Pa.; date to be announced later.

2. Selection of Doctor A. C. Seletzky, faculty counselor of the Student Branch at Case School of Applied Science, Cleveland, as chairman of the District committee on student activities, for the year beginning August 1, 1938.

3. Selection of Professor J. T. Walther to serve as the District student-counselor representative at the 1938 summer convention in Washington, D. C.

Asked for a "few remarks," President Harrison spoke briefly but forcefully and effectively on the subject "Minding Our Own Business." The theme of his brief address was to the effect that the important engineering requirements of the modern world can be met best by seasoned engineers having a broad background of experience. He urged engineering students to give primary attention to the acquisition of a sound and fundamental technical training, rather than to be led too far afield into other subjects during student days.

Inspection Trips and Entertainment

The variety of important industrial activities to be found in the vicinity of Akron afforded excellent opportunities for interesting and instructive inspection trips.

The principal event was the all-afternoon-and-evening trip to Nela Park, Cleveland, where some 300 of those attending the meeting were the guests of the General Electric Company. The program included escorted tours through the laboratories devoted to the experimental development and manufacture of electric lamps of various sizes, demonstration lectures on commercial and industrial illumination for the men and on home economics and illumination for the women, a generous dinner, and as a finale a demonstration lecture in the auditorium of the General Electric Institute covering briefly the evolution of illumination and some of the major contributions made by scientific research.

Another general event, heavily-attended was an evening trip to the Daniel Guggenheim Airship Institute where men and women alike enjoyed the inspection and demonstration of the vertical wind tunnel and its 110-mile-per-hour blast, various equipment for the pursuit of aeronautical research, and small-scale test models of dirigible aircraft. Although originally founded for research in the field of lighter-than-air craft, the Guggenheim Institute is now using available time and facilities for research in other suitable fields, such as mine ventilation as reported by Director Troller at one of the technical sessions.

A large group interested in power-plant equipment took advantage of the opportunity to visit the Barberton plant of the Babcock and Wilcox Company where the various fabrication processes incident to the manufacture of boilers, pulverized-coal equipment, and other power-plant equipment were witnessed in full swing under shop conditions. Of particular interest were the large and extremely heavy boiler drums being manufactured for new power plants where new levels of high pressures and temperatures are being pioneered.

A large crowd likewise attended the all-afternoon trip through the Barberton plant of the Ohio Brass Company, where the many steps in the manufacture of porcelain insulators of various types were followed through from their beginnings in raw material to their finishing, high-voltage testing, and packing into crates for shipment. The afternoon's program was topped off by a demonstration of the high-voltage laboratory equipment, featuring both commercial testing and some of the more spectacular high-voltage phenomena.

Automobile tire manufacture was followed through from crude rubber to finished product by a group that enjoyed the hospitality of the B. F. Goodrich Company. Various other special trips were arranged for other groups.

The women in attendance were generously provided for in the special features of the entertainment program. In fact, they were kept quite busy with a program starting with a guest luncheon Wednesday noon and providing a continuous series of activities that ended only with the concluding general banquet, Friday evening. The progam included an afternoon garden pilgrimage through the estates of F. A. Seiberling and L. A. Laurson, games and luncheon at the Portage Country Club, inspection of the Akron Air Dock and guest excursion on one of the Goodyear blimps, and a bridge-tea at the home of Mrs. A. O. Austin in Barberton.

COMMANDER ROSENDAHL DEFENDS DIRIGIBLES

Commander C. E. Rosendahl of the United States Navy, widely renowned for his pioneering efforts and leadership in the field of air navigation, spoke at the banquet on the subject "Lighter-Than-Air Craft." Commander Rosendahl carried all in the crowded banquet room along with him as he described and explained some of the more important features of lighter-than-air craft, and outlined his opinion of their inevitable and vitally important place in the field of modern transportation. He drew a convincing word picture of such craft in what he strongly termed "proper place"—as an important adjunct to other modes of transportation in the air and on the land and sea, and in both commercial and naval use.

In commercial transportation, Commander Rosendahl pictured the dirigible airship as a logical mode of long-distance high-speed travel, particularly on transoceanic routes where their "pay load" capacity and their long-range cruising ability he considers as already well-demonstrated by the world tour of the "Graf Zeppelin" and the long service of such craft in trans-Atlantic commercial service between Germany and South American ports. He emphatically assigned the "Hindenburg" disaster to the inflammability of hydrogen rather than to any defect in craft or handling. He stated that by its ability to maintain a continuous day and night air speed of about 85 miles an hour the modern dirigible aircraft could cross the Pacific in 4 days whereas the heavier-than-air craft now in that service require 6 days because of the necessity for intermittent flying and in spite of their higher speed when in the air.

For naval service, Commander Rosendahl considers the dirigible airship to be a vital part of the intelligence and scouting service, leaving the fighting to be done by planes and surface crafts better fitted for that service. The commander's talk was thoroughly understandable and well received.

DISTRICT EXECUTIVE COMMITTEE MEETING

The Middle Eastern District executive committee met in Akron, Saturday morning, October 16, following the District meeting, for a busy session involving a wide range of matters incident to District affairs and activities. Attendance at the meeting was recorded as follows:

I. Melville Stein, vice-president AIEE, presiding
H. A. Dambly, District secretary
M. W. Smith, District vice-chairman, membership committee
L. S. Billau, chairman, Baltimore Section
J. A. Noertker, chairman, Cincinnati Section
F. E. Harrell, chairman, Cleveland Section
W. L. Everitt, secretary, Columbus Section
W. D. Bearce, secretary, Erie Section
E. F. De Turk, chairman, Lehigh Valley Section
J. B. Harris, Jr., chairman, Philadelphia Section
W. A. Furst, secretary, Pittsburgh Section
H. S. Smith, chairman, Sharon Section
H. R. Daykin, secretary, Toledo Section
A. G. Ennis, representing Washington Section

Wichita Section Holds First Meetings

The organization meeting of the AIEE Wichita Section, authorized by the Institute's board of directors on June 24, 1937, was held September 16, 1937, at Wichita, Kans., with an attendance of 17. By-laws were adopted, and R. R. Miner (A'30) electrical engineer for the Kansas Gas and Electric Company, and W. A. Wolfe (A'30, M'36) relay engineer for the same company, were elected chairman and secretary-treasurer, respectively, to serve until August 1, 1938. Other members of the executive committee are E. E. Powell (A'37), G. LeRoy Quigley (A'32), and J. A. Rupf (A'33).

On September 30 a dinner meeting was held with 34 members and guests present. Doctor W. M. Jardine, president of the University of Wichita and former Secretary of Agriculture, was toastmaster, and speakers included L. T. Blaisdell (A'20, M'22) AIEE vice-president, whose subject was "The AIEE and the Electrical Engineering Profession."

Section committee chairmen are H. E. Margrave (A'37) membership; P. S. Colby (A'37) meetings and papers, and R. B. Gow (A'35) arrangements.

Former Edison Secretary Dead. At the age of 84, W. H. Meadowcroft, former secretary to Thomas A. Edison, died October 15, 1937, at his home in Boonton, N. J. Mr. Meadowcroft was born in Manchester, England, May 29, 1853, where he received his common and high school education. He came to the United States in 1875, and for the succeeding 6 years he was employed by the law firm of Carter and Eaton in New York City, being admitted to the New York bar in 1881. In that year he became affiliated with the Thomas A. Edison enterprises, and from 1910 until Edison's death in 1931 he was assistant and confidential secretary to Mr. Edison. Mr. Meadowcroft was founder and historian of the Edison Pioneers, of which organization he served as president in 1927. He was honorary vice-president of the Thomas Alva Edison Foundation, Inc., which was established in 1935 for the purpose of creating a living tribute to the inventor. He was the author of several books.

Training of Skilled Workers. A recent survey by the National Industrial Conference Board indicates that 4 out of every 5 companies have adopted some form of training for industrial work in order to meet present and future needs for skilled workers. The results of the board's survey, which included 473 companies in various industries and in different sections of the United States, are presented in a report, "Training for Industry." This report shows that training on the job is the method generally used, only 8.5 per cent of the companies surveyed maintaining so-called vestibule schools. Systematic apprentice training is reported by 272 companies, the time required ranging from one week to more than 5 years. Compensation is shown to be at least 50 per cent of the regular rate in over 90 per cent of the companies surveyed, and 80 per cent of the regular rate in about 32 per cent of the companies. Training is given to mature persons and regular employees as well as to youths and beginners, but in most companies not to persons under 18. Women as well as men are offered training opportunities in some companies.

Large Circuit Breaker Exhibited at Paris Fair

INTERRUPTEUR
AUTOMATIQUE
DELLE
à 500,000 Volts

CONSTRUCTED by Ateliers de Constructions Electriques de Delle, Villeurbanne, France, the circuit breaker and disconnecting switch shown here is being exhibited in the Palace of Light of the International Exposition of Paris. This unit, said to be the largest in the world, is designed for operation at 500 kv at 500 amperes and has an interrupting capacity of 5,000,000 kva.

Nomination of AIEE Officers for 1938 Election; Members' Suggestions Invited Until December 15

For the nomination of national officers to be voted upon in the spring of 1938, the AIEE national nominating committee will meet during the winter convention, January 24–28, 1938. To guide this committee in performing its constituted task, suggestions from the membership are, of course, highly desirable. To be available for the consideration of the committee, all such suggestions must be received by the secretary of the committee at Institute headquarters, not later than December 15, 1937.

In accordance with the provisions in the constitution and by-laws, as amended during 1935 and quoted in the following paragraphs, actions relative to the organization of the national nominating committee are now under way.

Constitution

28. There shall be constituted each year a national nominating committee consisting of one representative of each geographical district, elected by its executive committee, and other members chosen by and from the board of directors not exceeding in number the number of geographical districts; all to be selected when and as provided in the by-laws. The national secretary of the Institute shall be the secretary of the national nominating committee, without voting power.

29. The executive committee of each geographical district shall act as a nominating committee of the candidate for election as vice-president of that district, or for filling a vacancy in such office for an unexpired term, whenever a vacancy occurs.

30. The national nominating committee shall receive such suggestions and proposals as any member or group of members may desire to offer, such suggestions being sent to the secretary of the committee.
The national nominating committee shall name on or before January 31 of each year, one or more candidates for president, national treasurer, and the proper number of directors, and shall include in its ticket such candidates for vice-presidents as have been named by the nominating committees of the respective geographical districts, if received by the national nominating committee when and as provided in the by-laws; otherwise the national nominating committee shall nominate one or more candidates for vice-president(s) from the district(s) concerned.

By-Laws

Sec. 22. During September of each year, the secretary of the national nominating committee shall notify the chairman of the executive committee of each geographical district that by December 15 of that year the executive committee of each district must select a member of that district to serve as a member of the national nominating committee and shall, by December 15, notify the secretary of the national nominating committee of the name of the member selected.
During September of each year, the secretary of the national nominating committee shall notify the chairman of the executive committee of each geographical district in which there is or will be during the year a vacancy in the office of vice-president, that by December 15 of that year a nomination for a vice-president from that district, made by the district executive committee, must be in the hands of the secretary of the national nominating committee.
Between October 1 and December 15 of each year, the board of directors shall choose 5 of its members to serve on the national nominating committee and shall notify the secretary of that committee of the names so selected, and shall also notify the 5 members selected.
The secretary of the national nominating committee shall give the 15 members so selected not less than 10 days' notice of the first meeting of the committee, which shall be held not later than January 31. At this meeting, the committee shall elect a chairman and shall proceed to make up a ticket of nominees for the offices to be filled at the next election. All suggestions to be considered by the national nominating committee must be received by the secretary of the committee by December 15. The nominations as made by the national nominating committee shall be published in the March issue of Electrical Engineering (Journal of AIEE), or otherwise mailed to the Institute membership not later than the first week in March.

Independent Nominations

Independent nominations may be made in accordance with provisions in Section 31 of the constitution and Section 23 of the by-laws, which are quoted below:

Constitution

31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the national secretary when and as provided in the by-laws; such petitions for the nomination of vice-presidents shall be signed only by members within the district concerned.

By-Laws

Sec. 23. Petitions proposing the names of candidates as independent nominations for the various offices to be filled at the ensuing election, in accordance with Article VI, Section 31 (constitution), must be received by the secretary of the national nominating committee not later than March 25th of each year, to be placed before that committee for the inclusion in the ballot of such candidates as are eligible.
On the ballot prepared by the national nominating committee in accordance with Article VI of the constitution and sent by the national secretary to all qualified voters during the first week in April of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

(*Signed*) H. H. Henline,
November 1, 1937 *National Secretary*

Lehigh Valley Section Sponsors Joint Meeting

An engineers' dinner meeting, attended by more than 400 persons, was held at the Jermyn Hotel, Scranton, Pa., October 9, 1937, under joint sponsorship of the AIEE Lehigh Valley Section, the local sections of the American Institute of Mining and Metallurgical Engineers, and The American Society of Mechanical Engineers, and the chambers of commerce of Scranton, Wilkes-Barre, Hazleton, and Pottsville. A report of the meeting was made available by W. H. Lesser (M'24) of J. H. Pierce and Company, Scranton, a past-chairman of the Lehigh Valley Section, who was chairman of the committee on arrangements and who also acted as toastmaster and presiding officer at the meeting.

Following the dinner those attending heard 3 addresses; 2 speakers dealt with the anthracite coal industry, one of the chief industries of the Lehigh Valley Section, and the other was concerned with one phase of the electrical industry. In the first talk of the evening Philip Sporn (A'20, F'30) vice-president and chief engineer of the American Gas and Electric Company, New York, N. Y., outlined broadly, yet using some specific examples to illustrate his assertions, the operation of electric power systems on an interconnected and co-ordinated basis. He stated that "the development of the electric utility systems of the United States on an interconnected and co-ordinated basis has resulted in giving the United States a pre-eminent position in the field of electric power supply." In the next address, Cadwallader Evans, Jr., vice-president and general manager of the Hudson Coal Company, Scranton, spoke on "Looking Ahead in Anthracite," outlining some of the operating problems in the coal-mining industry and sketched its future as it appears today. The latest efforts of the anthracite industry to promote the sale of its product were described by the third speaker, Frank W. Earnest, Jr., president of Anthracite Industries, Inc., New York, N. Y. He emphasized the improved competitive position of the anthracite industry, and painted a bright picture of the future of that business. This was the second of 2 such jointly sponsored meetings, the first having been held in October 1935 at Wilkes-Barre, Pa.

Winter Convention to Include General Session

Because the "general session" held during the Institute's 1937 summer convention at Milwaukee, Wis., evoked so much interest, a somewhat similar session is being arranged for the forthcoming 1938 AIEE winter convention to be held in New York, N. Y., January 24–28. According to present plans, a speaker of national repute will address the session on a subject of broad interest to the engineering profession, and to electrical engineers in particular. A special committee to make the necessary arrangements for the session has been appointed consisting of the following: H. S. Bennion, C. R. Beardsley, L. W. W. Morrow, H. S. Osborne, and W. E. Wickenden.

Although the technical program is still in the formative stage, sessions on the following subjects are tentatively scheduled: electronics, communication, electrical machinery, power transmission and distribution, protective devices, transportation, instruments and measurements, education, electric welding, research, and basic sciences. In addition, several technical conferences are expected to be held; 3 such conferences already have been tentatively scheduled, one on active networks under sponsorship of the committee on communication, and 2 under sponsorship of the committee on basic sciences.

Details concerning these and other features of the convention program will be included in a later issue of Electrical Engineering.

New ASTM Standards. At a recent meeting of committee *E*-10 on standards of the American Society for Testing Materials, 11 new tentative standards were recommended. Among these were the following, covering specifications and test methods for electrical materials:

1. Specifications for Phenolic Laminated Sheet for Radio Applications (*D* 467–37 *T*).
2. Method of Testing Pin-Type Soda-Lime Glass Insulators (*D* 468–37 *T*).
3. Methods of Test for Rubber Insulated Wire and Cable (*D* 470–37 *T*).

Fifth Annual Meeting of ECPD Held; Accrediting of Engineering Curricula Extended

THE fifth annual meeting of Engineers' Council for Professional Development was held October 1, 1937, in the Engineerng Societies Building, New York, N. Y. Election of officers, appointment of committees, and presentation of the annual reports of Council's committees constituted the principal items of business. Council approved the accrediting of additional curricula in engineering schools, as recommended by the committee on engineering schools, making a total of 442 curricula now accredited in 127 institutions (see tabulation elsewhere in this report).

Excerpts from the complete reports of the committees on student selection and guidance, professional training, and engineering schools follow the item on election of officers and appointment of committees; the report of the committee on professional recognition was held over as an order of business for a later meeting of ECPD executive council, and was referred back to the committee for further consideration.

Chairman Chas. F. Scott (A'92, F'25, HM'29, past-president) in opening the meeting presented a prepared review of ECPD's activities to date, calling attention to its principal objectives and outlining various possibilities for increased effectiveness of ECPD's efforts as a joint agency for the engineering societies. "Supplementing 'general objectives' in our charter," said Doctor Scott, "is an 'immediate objective'—the development of the young engineer for some 10 years from high school to professional recognition. It is in several stages. In the pre-freshman stage ECPD is to present 'the responsibilities and opportunities of engineers'; in engineering schools it is to 'formulate... a sound educational foundation for the practice of engineering'; and after graduation it is to 'further personal and professional development of young engineering graduates.' "

Elections and Appointments Reported

Chas. F. Scott, professor of electrical engineering emeritus, Yale University, was reelected ECPD chairman. A. B. Parsons, secretary of the American Institute of Mining and Metallurgical Engineers, was elected secretary, and C. E. Davies, secretary of the American Society of Mechanical Engineers, was re-elected assistant secretary of Council. Chairmen of 3 ECPD committees were re-elected as follows: student selection and guidance, R. L. Sackett, dean emeritus of college of engineering, Pennsylvania State College; engineering schools, Karl T. Compton (F'31), president, Massachusetts Institute of Technology; and professional recognition, C. N. Lauer, president, Philadelphia (Pa.) Gas Works. O. W. Eshbach (A'17, F'37) American Telephone and Telegraph Company, New York, N. Y., was appointed chairman of the committee on professional training; he has served as acting chairman since the death of General R. I. Rees, former chairman of the committee.

Executive committee members reappointed were: J. P. H. Perry, representing the American Society of Civil Engineers; C. F. Hirshfeld (A'05, F'36) representing the American Society of Mechanical Engineers; L. W. W. Morrow (A'13, F'25, director) representing the AIEE; H. C. Parmelee, representing the American Institute of Chemical Engineers; and D. B. Steinman, representing the National Council of State Boards of Engineering Examiners. Members newly appointed to the executive committee were: D. C. Jackson (A'87, F'12, past president) representing the Society for the Promotion of Engineering Education [alternate R. E. Doherty (A'16, M'27)]; and W. B. Heroy, representing the American Institute of Mining and Metallurgical Engineers.

Appointments of representatives of the participating societies for the 3-year term 1937–40 were announced as follows: ASCE, J. P. H. Perry (reappointment); ASME, A. R. Stevenson, Jr. (reappointment); AIME, W. B. Heroy; AIChE, B. F. Dodge; SPEE, R. E. Doherty; AIEE, F. Ellis Johnson; NCSBEE, J. S. Dodds.

Report of Committee on Professional Training

O. W. Eshbach, Acting Chairman

The untimely death, during the past year, of the chairman, General R. I. Rees, seriously affected progress toward the objectives expressed in previous reports. His full time activity being essential to the realization of the year's program, it became necessary to adjust the work of the committee to more restricted projects.

The program recommended in the 1936 report may be simply expressed in terms of 3 general objectives.

1. To prepare and distribute information which would stimulate and assist junior engineers in self-development.
2. To give assistance in local organization of juniors so as to provide means of achieving their objectives.
3. To study the desires and needs of younger engineers as their activities develop and ideas crystallize, so that additional efforts can be made most effective.

While substantial progress has been made in the first 2 objectives, not much has been achieved in obtaining a better understanding of future needs. By nature, this is a continuing problem, varying in time and locality. It requires an accumulation of experience and the constant attention of the committee as local activities develop.

Local Organizations and Activities. At the 1936 annual meeting, the committee considered as its second major undertaking for 1936–37 the stimulation of programs similar to that at Providence in an increasingly large number of centers, having local sections of the constituent bodies and junior engineers form the basis of operations. The success of the Providence trial organization, which has continued its activities during the past year and reports of their experience given wide circulation, prompted General Rees to plan a trip in October and November, 1936, to Cleveland, Chicago, St. Louis, Detroit, and Pittsburgh to discuss the development of junior programs in these areas. Plans were interrupted by his sudden death in Detroit, on November 23. Through the voluntary assistance of Doctor C. F. Hirshfeld, joint meetings with representatives of local engineering societies and the national societies were held in both Detroit and Chicago, completing the itinerary. As a result of these visits, active organization work has been undertaken and plans are in progress for this fall to initiate further progress in junior activities. In addition to the activities started by General Rees, junior committees have been formed in Hartford and Boston and are being considered by the Worcester Engineering Society.

During the spring and summer the committee has been studying the trend of junior organization developments. From reports of the participating societies and other sources, it was found that some form of junior organization, sponsored either jointly or separately by local sections of the national societies, was in existence or being formed in 39 localities.

While recent in origin most of these organizations have come about through the normal activities of the sections of national societies. In most cases they are sponsored by a single society but include in their membership juniors of other affiliations. The spontaneity of these developments is encouraging. They present opportunities for co-operation which should be considered jointly by the sections in the several localities.

Principles of Organization of Local Activities. The principal objective of local organization has been to afford opportunity for personal development in accord with the ideals set forth by the ECPD. The general and sequential procedure in starting junior activities has been as indicated in many letters and reports as follows:

1. The selection of experienced engineers of the community who have expressed interest and willingness to act as advisors and a group of junior engineers representative of different professional interests.
2. Effecting an organization of juniors which gives opportunity for them to frame their own ideas as to the form it takes.
3. Encouraging the development of a serious and effective program of activity consistent with the wishes of the group and the ideals of the purpose.

While this general statement typifies the procedures followed, the initiation by the advisors or originators may come in 3 different ways.

1. Local engineering clubs may sponsor the junior organization through representatives of their professional divisions and thus effect co-ordination with the section activities of the national engineering societies.
2. Representatives of the several sections of the national societies may undertake to start and co-ordinate junior activities by forming a special joint activity or junior advisory committee.
3. The sections of national societies may act independently and not concurrently.

The first 2 ways have the advantage of co-ordination in programs of social and professionally common interests. The last has the advantage of flexibility and speed in getting underway but the disadvantage of lack of co-ordination in matters of common interest and united effort toward the stimulation of professional unity.

In whatever manner these organizations originate it seems desirable that they should be the accomplishment of local sections of the constituent bodies of ECPD and that the committee on professional training should aim to give the constituent bodies such assistance as necessity requires and is reasonable to provide. In this connection there is at present no common committee organization within local sections, and no common classification of membership which together with reasonably uniform section areas would greatly enhance the opportunity for local and national co-operation.

Junior Committee Recommendations. The annual report of the junior committee in 1936 stresses as important problems:

1. Stimulation of junior interest in the entire ECPD program.
2. Organization of groups in local areas.
3. Development of training material.
4. Development of means of qualifying for professional recognition.

During the year progress has been made by ECPD in the first 2 problems. During the coming year the committee on professional training plans to study the junior programs now in progress and give attention to such needs as are in evidence.

Publications and Their Distribution. Since the organization of ECPD the committee on professional training has prepared and published the following pamphlets, among others:

"Suggestions to Junior Engineers." A personal appraisal blank to assist in planning a definite program of development; supplemented by a nontechnical reading list, classified under 10 general subjects.

"Selected Bibliography of Engineering Subjects." A selection of widely recommended texts, mostly of college grade, prepared with the co-operation of over 100 practicing engineers and teachers in 1937:
I. Mathematics, mechanics, and physics
II. Aeronautical and civil engineering
III. Chemical and industrial engineering
IV. Electrical and mechanical engineering
V. Metallurgical and mining engineering

"University Extension Facilities." A list of 24 institutions with description of nontechnical courses given by class study or by correspondence. Prepared by the junior committee in 1935.

During the past year considerable effort was spent in the final editing of the "Selected Bibliography of Engineering Subjects" and its distribution. Copies were sent to all who co-operated in its preparation, the deans of engineering schools, selected publishers of trade magazines, and librarians. The listing of all ECPD publications in the sections of the bibliography was called to the attention of the recipients with the purpose of affording teachers and others the opportunity of directing the attention of students to the interest of the profession in their development, and expediting individual efforts in organizing programs of self-development after graduation. Thus there have been made available at nominal fees an aid for self-analysis, references for both cultural and technical study, and suggestions of study facilities through university extension. To further publicize the program of Council and emphasize the need for continued development, the committee has prepared a small folder, appendix *C*1, and recommends a wide distribution of it to fill the need which has been felt for a short account of the organization, purpose, plans and accomplishment of ECPD. The reprinting of selected articles, both by ECPD and in engineering magazines, is also recommended to aid in reports of progress and better understanding of aims and activities. In this connection 2 articles were reprinted by the committee and several appeared in national societies' publications. A particularly well-prepared article on "The Providence Experiment in Junior Engineers' Development" was reprinted from *Chemical and Metallurgical Engineering*, volume 44, March 1937, and distributed through the national societies to the sections of their societies. It is hoped that as progress in other localities is reported the details of their experiences may be publicized in similar manner.

Report of Committee on Student Selection and Guidance

R. L. Sackett, Chairman

English and Mathematics Tests. The study of the academic history of entering engineering students who were given the co-operative tests in English and mathematics in 1933 and 1934 has been continued. Results noted in previous reports are confirmed by the evidence from the 12 institutions giving the tests. Of those students who discontinued, the larger proportion dropped out voluntarily because of dissatisfaction with themselves, lack of finances, or other conditions. It is safe to say that some had little or no effective guidance and if they had received good counsel, would not have undertaken an engineering education. Scholarship, sound objectives, the will to win, or other qualifications were lacking. The English and mathematics tests indicated that these individuals were invariably low grade for educational refinement. That the lack of the scholarship which is required for reasonable success in engineering education can be detected by such tests, or others, or by examination of the high-school record, is beyond dispute.

Engineering: A Career—A Culture. The more general use of the pamphlet of this title is a source of satisfaction. The subcommittee has revised the material and is prepared to submit a copy for a new and improved edition as soon as the present one is exhausted.

Guidance Manual. The "Manual on Guidance," prepared by the committee, is being used increasingly and is helpful to the committees of engineers, to colleges, and to high schools. It has been mimeographed and distributed, without charge, to those vitally interested.

High-School Guidance. A notable increase in interest in the subject of guidance for high-school students has been observed. Articles in magazines and in the daily press are evidence of the growing appreciation of the economic and social importance of sound vocational counsel.

Selection by the College. To cull some 20,000 prospective engineering freshmen from hundreds of thousands of seniors, in thousands of high schools, for entrance to 150 engineering schools, is a mighty task. Upon it, however, depend the careers of individuals, the efficacy of engineering schools, the quality of the engineering profession, and its contribution to the interest of the general public. The usefulness of the engineer depends on personality as well as technical proficiency.

The increase in college enrollments has brought financial and social problems of grave importance.[*] Limiting enrollments has been suggested but no generally accepted basis for restriction has yet been found. Various methods have been used, such as college board examinations and batteries of training and aptitude tests. There is no doubt that limiting enrollment in engineering to those of high scholastic standing, judged by the 4-year high- or preparatory-school record, is distinctly helpful.

In order to assist in better precollege guidance, engineering schools have been urged to use their influence and faculties in promoting better guidance in the high schools within their spheres of influence.

Guidance by Engineering Societies. The national engineering societies have been urged to organize local committees of interested engineers who approach the public-school authorities and offer their services as counselors to students who are interested in engineering. The purpose is to bring the student into closer contact with the realities of engineering education and the practical work which the engineer does—especially the young engineer. Among the cities which have made a notable success of such joint efforts are Detroit, Denver, Milwaukee, Kansas City, Rochester, and St. Louis.

Selective Tests. Search, experiment, and evaluation of tests suitable for extracting aptitudes of importance in the prospective engineering student are being conducted by various psychologists and committees. The validity has not yet been established or the committee has not yet had data submitted to it to establish the value of new tests or small groups of tests. That tests of value have been or will be established is beyond doubt. That they may be of great assistance in guidance and selection is equally certain. But discretion in their use and judgment are also necessary in their application. A large measure of responsibility will still rest on those using tests to evaluate personal qualities which tests cannot be expected to expose, at least in the present state of the art.

Guidance in Public Schools. City schools are organizing public programs followed by personal counsel for those desirous of entering one of the professions. The majority of the better high schools have counselors and are developing guidance for those thinking of engineering or other vocations. In some of them there is a definite need for an experienced approach to the subject. This, the practicing engineer can supply if he has the interest and an understanding of what youth needs in the way of information about the demands made on the novitiate and the later rewards. More emphasis should be placed on interests, aptitudes, ambitions, and personal qualities and less on "how much does it pay?"

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[*] W. M. Kotschnig, *The Educational Record*, July 1937.

List of Undergraduate Curricula of Educational Institutions Accredited by ECPD

(As of October 1, 1937, and subject to continual revision)

University of Alabama: Aeronautical, civil, electrical, industrial, mechanical, mining

University of Arizona: Civil, electrical, mechanical, mining

University of Arkansas: Civil, electrical, mechanical

Armour Institute of Technology: Chemical, civil, electrical, mechanical

Brown University: Civil, electrical, mechanical

Bucknell University: Civil, electrical

University of California: Civil, electrical, mechanical, metallurgical (metallurgy), mining, petroleum

California Institute of Technology: Aeronautical (6-year course), chemical (5-year course), civil, electrical, mechanical

Carnegie Institute of Technology: Chemical, civil (*a*), electrical (*a*), industrial (management) (*a*), mechanical (*a*), metallurgical (*a*)

Case School of Applied Science: Chemical, civil, electrical, mechanical, metallurgical

University of Cincinnati: Aeronautical, chemical, civil, electrical, mechanical

The Citadel: Civil

Clarkson College of Technology: Civil, electrical, mechanical

Clemson Agricultural College: Civil, electrical, mechanical

College of the City of New York (*a*): Civil, electrical, mechanical

University of Colorado: Architectural, civil, electrical, mechanical

Colorado School of Mines: Geological, metallurgical, mining, petroleum

Columbia University (*b*): Chemical, civil, electrical, industrial, mechanical, metallurgical, mining

Cooper Union Institute of Technology (*c*): Civil, electrical, mechanical

Cornell University: Chemical, civil, electrical, industrial (administrative), mechanical

Dartmouth College: Civil

University of Delaware: Civil, electrical, mechanical

University of Detroit: Aeronautical, architectural, civil, electrical, mechanical

Drexel Institute: Chemical, civil, electrical, mechanical

Duke University: Civil, electrical, mechanical

University of Florida: Civil, electrical, industrial, mechanical

Georgia School of Technology: Aeronautical, civil (*d*), electrical (*d*), mechanical (*d*)

Harvard University (*e*): Civil, communication, electrical, industrial (engineering and business administration), mechanical, metallurgical (physical metallurgy), sanitary

Howard University: Civil, electrical, mechanical

University of Idaho: Civil, electrical, mechanical

University of Illinois: Architectural, ceramic (technical option), chemical, civil, electrical, general (*f*), mechanical, metallurgical, mining

Iowa State College: Agricultural (*g*), architectural, chemical, civil, electrical, general (*f*), mechanical

State University of Iowa: Chemical, civil, electrical, mechanical

Johns Hopkins University: Civil, electrical, mechanical

University of Kansas: Architectural, civil, electrical, mechanical, mining

Kansas State College: Agricultural (*g*), architectural, civil, electrical, mechanical

University of Kentucky: Civil, metallurgical, mining

Lafayette College: Civil, electrical, industrial (administrative), mechanical, metallurgical, mining

Lehigh University: Chemical, civil, electrical, industrial, mechanical, metallurgical, mining

Louisiana State University: Civil, electrical, mechanical, petroleum

University of Louisville: Chemical, civil, electrical, mechanical

University of Maine: Civil, electrical, general (*f*), mechanical

Marquette University: Civil, electrical, mechanical

University of Maryland: Civil, electrical, mechanical

Massachusetts Institute of Technology: Aeronautical, architectural, building engineering and construction, chemical, civil, electrical, electrochemical, general (*f*), industrial (business and engineering administration), mechanical, metallurgical (metallurgy), mining, naval architecture and marine engineering, public health, sanitary

University of Michigan: Aeronautical, chemical, civil, electrical, engineering mechanics, mechanical, metallurgical, naval architecture and marine engineering, transportation

Michigan College of Mining and Technology: Civil, electrical, mechanical, metallurgical, mining

Michigan State College: Civil, electrical, mechanical

University of Minnesota: Aeronautical, chemical, civil, electrical, mechanical, metallurgical, mining (excluding mining in geology option), petroleum

University of Missouri: Civil, electrical, mechanical

Missouri School of Mines and Metallurgy: Ceramic, civil, electrical, metallurgical, mining (mine) (excluding mining geology option)

Montana School of Mines: Geological, metallurgical, mining

Montana State College: Civil, electrical, mechanical

University of Nebraska: Agricultural (*g*), architectural, civil, electrical, mechanical

University of Nevada: Electrical, mining

University of New Hampshire: Civil, electrical, mechanical

University of New Mexico: Civil, electrical, mechanical

New York University: Aeronautical, chemical (*h*), civil (*a*), electrical (*a*), mechanical (*a*)

New York State College of Ceramics (at Alfred University): Ceramic

Newark College of Engineering: Civil, electrical, mechanical

North Carolina State College: Ceramic, civil, electrical, mechanical

University of North Dakota: Civil, electrical, mechanical, mining

Norwich University: Civil, electrical

Ohio State University: Ceramic, chemical, civil, electrical, industrial, mechanical, metallurgical, mining (mine)

University of Oklahoma: Architectural, civil, electrical, mechanical, petroleum (production option)

Oklahoma Agricultural and Mechanical College: Civil, electrical, industrial, mechanical

Oregon State College: Civil (excluding business option), electrical (excluding business option), mechanical (excluding business option)

University of Pennsylvania: Chemical, civil, electrical, mechanical

Pennsylvania State College: Architectural, chemical, civil, electrical, electrochemical, industrial, mechanical, sanitary

University of Pittsburgh: Chemical, civil, electrical, industrial, mechanical, metallurgical, mining, petroleum, petroleum refining

Polytechnic Institute of Brooklyn: Chemical (*h*), civil (*a*), electrical (*a*), mechanical (*a*)

Princeton University: Chemical, civil, electrical, mechanical

Purdue University: Chemical, civil, electrical, mechanical

Rensselaer Polytechnic Institute: Chemical, civil, electrical, mechanical

Rhode Island State College: Civil, electrical, mechanical

Rice Institute: Civil, electrical, mechanical

University of Rochester: Mechanical

Rose Polytechnic Institute: Civil, electrical, mechanical

Rutgers University: Civil, electrical, mechanical, sanitary

University of Santa Clara: Civil, electrical, mechanical

South Dakota State College: Civil electrical, mechanical

South Dakota State School of Mines: Civil, electrical, metallurgical, mining

University of Southern California: Petroleum

Stanford University: Civil, electrical, mechanical, metallurgical, mining, petroleum

Stevens Institute of Technology (*f*): General

Swarthmore College: Civil, electrical, mechanical

Syracuse University: Civil, electrical, industrial (administrative), mechanical

University of Tennessee: Civil, electrical, mechanical

University of Texas: Civil, electrical, mechanical, petroleum (petroleum production)

Agricultural and Mechanical College of Texas: Civil, electrical, mechanical, petroleum

Texas Technological College: Civil, electrical, mechanical

Tufts College: Civil, electrical, mechanical

Tulane University of Louisiana: Civil, electrical, mechanical

Union College: Civil, electrical

University of Utah: Civil, electrical, mechanical, metallurgical, mining

University of Vermont: Civil, electrical, mechanical

University of Virginia: Civil, electrical, mechanical

Virginia Military Institute: Civil, electrical

Virginia Polytechnic Institute: Civil, electrical, industrial, mechanical

Washington University: Architectural, civil, electrical, industrial (administrative), mechanical

University of Washington: Aeronautical, ceramic, chemical, civil, electrical, mechanical, metallurgical, mining

State College of Washington: Civil electrical (basic and hydroelectric, options), mechanical (basic option), metallurgical, mining (excluding mine administration and petroleum engineering option)

Webb Institute of Naval Architecture: Naval architecture and marine engineering

West Virginia University: Civil, electrical, mechanical, mining

University of Wisconsin: Chemical, civil, electrical, mechanical, metallurgical, mining

Worcester Polytechnic Institute: Civil, electrical, mechanical

Yale University: Chemical, civil, electrical, mechanical, metallurgical

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(*a*). Accrediting applies to both the day and evening curricula.

(*b*). Accrediting applies to the 4-year and 5-year curricula leading to the bachelor of science degree.

(*c*). Accrediting applies to day curriculum only. Action on evening curriculum deferred pending granting of degrees.

(*d*). Accrediting applies to both regular and co-operative curricula.

(*e*). Accrediting applies only to curriculum as submitted to ECPD and upon completion of which a certificate is issued by Harvard University certifying that the student has pursued such a curriculum.

(*f*). The accrediting of a curriculum in general engineering implies satisfactory training in engineering sciences and in the basic subjects pertaining to several fields of engineering; it does not imply the accrediting, as separate curricula, of those component portions of the curriculum such as civil, mechanical, or electrical engineering that are usually offered as complete professional curricula leading to degrees in these particular fields.

(*g*). All curricula in agricultural engineering which appear in this list have been provisionally accredited for a period of 2 years. The reason for this is twofold; in the first place it appears to ECPD that the final year of the 4-year programs fails to build, in adequate manner, upon the engineering basis laid in the first 3 years; secondly, it is the feeling of ECPD that curricula in agricultural engineering might more properly be given as options under one of the major engineering branches (that is, civil engineering, electrical engineering, or mechanical engineering).

(*h*). ECPD has not received from its subcommittee on chemical engineering a recommendation with respect to the evening curriculum in chemical engineering.

Cost of Lack of Guidance. For lack of adequate guidance a considerable number of boys drop out at the end of or during the first year. There is a definite financial loss in each case. Much has been said about the intangible profit of going to college even one year. The statistics of engineers do not show tangible values for one or 2 years of college life. On the contrary, the moral and psychological effects of failure are serious and real. The sense of defeat is a handicap at a critical period in the life of youth struggling for a foothold.

Some 20,000 students, more or less, are asking admission to engineering colleges this fall. Two things should be done to prevent economic loss and to protect the engineering profession. First, there should be conscientious guidance provided by the schools, by colleges, and with the aid of the profession. Second, colleges should abandon competition for numbers and accept only those who can meet certain well-defined standards which promise a fair measure of achievement in engineering education and in their future business and professional careers.

Report of Committee on Engineering Schools

Karl T. Compton, Chairman

The committee on engineering schools is expected, as its broad responsibility, "to formulate criteria for colleges of engineering, which will insure to their graduates a sound educational background for practicing the engineering profession." In order that the committee might carry out most effectively its broad program, the decision was made during its first year that the early efforts of the committee should be directed solely toward the accrediting of undergraduate curricula in engineering. There seemed to be a pressing need for a thoroughly representative and authoritative accrediting agency. While the committee recognized that the theoretical desirability of accrediting might be subject to considerable differences in opinion, it further recognized that various factors, including state licensing laws, were resulting in numerous unco-ordinated efforts to establish lists of accredited engineering colleges. In ECPD there seemed to exist an organization representing the entire profession, and thus ideally constituted to administer a plan for accrediting engineering curricula both uniformly and in a manner consistent with the high ideals of the engineering profession. (The basis for accrediting was published as part of report of the fourth annual meeting of ECPD in ELECTRICAL ENGINEERING for November 1936, pages 1280–5.)

In October 1936, an initial list of the curricula in 2 regions of the United States, judged by ECPD to be worthy of accrediting, was released for publication. Arrangements were made in the early spring of 1936 to extend the program into the remaining regions of the United States and to examine the institutions in the first 2 regions which had not applied in time for consideration during 1935–36. Ninety-five institutions submitted curricula, involving visits of inspection to 88 institutions during the year 1936–37. The remaining 7 institutions have asked for inspection during the year 1937–38.

Summary of Institutions and Curricula Inspected. Since the accrediting program was inaugurated in 1935, a total of 134 degree-granting engineering schools have submitted 642 curricula for accrediting. Of this number 127 institutions have been visited to date and recommendations prepared on 617 curricula. The records of the committee show that 20 degree-granting engineering colleges have not yet responded to the invitation of the committee.

Summary of Recommendations. The following is a summary of the actions recommended to ECPD by the committee for the 617 curricula inspected up to the present time:

To accredit	373
To accredit provisionally for a limited period	69
To defer action	35
Not to accredit	140
Total	617

Provisional accrediting has ranged from periods of one to 3 years and involves a revisit at the end of the period of accrediting. (In all other cases review is left entirely to the discretion of ECPD and its committee on engineering schools.) Deferred action has been taken where degrees have not yet been conferred, or where recommendations in regard to curricula in chemical engineering are still under consideration by the committee on chemical engineering education of the American Institute of Chemical Engineers. A complete list of the accredited curricula by institutions may be found elsewhere in this report.

By-Products of Accrediting. The main objective of the accrediting program, of course, has been to draw up a list of engineering curricula which, in the opinion of ECPD, represent sound and adequate instruction in the several branches of engineering. A second objective, however, has come to be regarded as being fully as important, namely, to be of the greatest possible aid to the institutions offering curricula for accrediting.

Almost without exception the visiting committees have been asked by the administrative officers of the institutions visited to give them suggestions and advice. The committees have endeavored to comply with these requests, and throughout the discussions of the regional committees, and of the general committee later, a great deal of attention has been given to the consideration of directions along which substantial improvements might be made which would increase the effectiveness of the teaching program of the institution. In many instances the opinion of the ECPD committee has been the deciding factor in making long-desired changes or improvements possible. In other cases the wide experience and fresh perspective of the delegatory committee members have made it possible to call to the attention of the officers of administration undesirable conditions which had remained unnoticed or neglected. That the suggestions of the committees have been appreciatively received may be seen both from the letters which have been written, and from the way in which the suggestions have been acted upon.

At present there is every indication that the accrediting program will result not only in a generally accepted accredited list, for which there is a real need, but also in a definite stimulation to higher excellence in our engineering schools, and a wide distribution among the institutions, particularly among the various officers of administration, of some of the best ideas in engineering education.

Activities in Prospect. Since the organization of the committee on engineering schools in 1932, attention has been focused almost solely upon the accrediting program. It has seemed recently that this project is now sufficiently well in hand to permit the consideration of other ways in which the committee could be of service. Accordingly, during the past year the committee has discussed several activities in which it might engage over a period of perhaps 5 years. Not all of these activities would, or could, be undertaken at once. Their possibilities are, however, being further studied, and the consideration of them will require a substantial portion of the committee's time during the ensuing year. These activities are:

(*a*). Continuation of accrediting program. The committee must necessarily make this its first concern. Plans for the periodic review and reinspection of accredited curricula were outlined roughly during the past year, and these will shortly be put into operation.

(*b*). Investigation of graduate study. The committee has recently considered this aspect of accrediting and come to the conclusion that there may be other more effective means of enhancing the status of graduate study.

(*c*). Study of admission with advanced standing. During the consideration of undergraduate curricula, it has become evident to the committee that the qualifications of an engineering student who transfers to an engineering school with advanced standing, in particular from an institution of a different type, such as a college of liberal arts or a junior college, are dependent to a considerable extent upon the quality of the instruction which he received in the institution from which he is transferring. It further is evident that the quality of work maintained at any institution is affected by the standards at other institutions which prepare students for entrance with advanced credit. It appears, therefore, to be within the scope of the committee to consider ways and means of improving standards at the junior colleges, colleges of liberal arts, other engineering schools, and divisions serving as feeders for institutions which have had curricula accredited by ECPD. A committee has been appointed to pursue the study of this problem.

(*d*). Advisory service to institutions. In view of the considerable experience and background which the delegatory committee members have gained during the course of the accrediting program, the committee should be in a position to be of material assistance to institutions offering engineering curricula by making available to interested institutions an informal advisory service. Recognizing that its experience creates a responsibility in this direction, the committee is prepared to perform such a function and is ready, on request, to advise or confer with representatives of engineering colleges in reference to any phase of their work related to accrediting.

(*e*). Survey of engineering education. During the course of its operations, the committee has assembled a great deal of valuable information on the status of engineering education. It appears highly desirable that this material be analyzed and published while it is yet fresh.

Index to ASTM Proceedings. A complete subject and author index covering the contents of volumes 31 to 35, inclusive, of the ASTM *Proceedings*, issued from 1931 to 1935, is now available from the American Society for Testing Materials, 260 South Broad Street, Philadelphia, Pa. Prices may be obtained from the society.

Chemistry Subcommittee of NRC Insulation Committee Meets at Rochester

UNDER auspices of the physical and inorganic division of the American Chemical Society, at its annual convention at Rochester, N. Y., the subcommittee on chemistry of the insulation committee of National Research Council held a symposium on insulation materials, September 9, 1937. Kenneth S. Wyatt (A'32) research engineer for The Detroit (Mich.) Edison Company, and chairman of the subcommittee, who furnished the material from which this report was prepared, presided over the session, at which 5 papers were presented:

1. Dipole Polarization and Dielectric Loss in Certain Liquids and Solids, S. O. Morgan, Bell Telephone Laboratories, Incorporated, New York, N. Y.

2. Electric Breakdown of Solid and Liquid Insulators, A. von Hippel (M'37), Massachusetts Institute of Technology, Cambridge.

3. The Influence of Gaseous Electric Discharge on Hydrocarbon Oils, L. J. Berberich (A'30, M'36) Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

4. Methods of Measuring the Electrical Properties of Solids, R. M. Fuoss, General Electric Company, Schenectady, N. Y.

5. Electrical and Chemical Studies of Oil Oxidation, J. C. Balsbaugh (A'23, M'25), Massachusetts Institute of Technology, Cambridge.

In a brief introductory outline of the objectives of the symposium Chairman Wyatt pointed out that "insulating materials find an extremely wide and indispensable place in the electrical industry, and that the development and research leading to improved insulating materials, the manufacture and processing of present materials, and the study of deterioration in service are to a large extent chemical problems. Yet the burden of the attack so far has rested on the shoulders of electrical engineers and physicists rather than chemists. To insure the most rapid progress it will be necessary to enlist to a greater extent the services of the chemists."

Technical Session

Dipole Polarizations and Dielectric Loss. S. O. Morgan, in presenting his paper, asserted that although generally the function of dielectrics is considered to be the hindering of current flow from one conductor to another, or from a conductor to its surroundings, for many purposes the function of dielectrics is to permit the flow of alternating current.

"No insulator permits the flow of current without at least a small amount of energy being dissipated as heat. One of the tasks of the engineer is to obtain a maximum permittivity or dielectric constant with a minimum of dielectric loss. Dielectric theories predict that a high dielectric loss is a necessary consequence of a high dielectric constant. Experimental data for a wide variety of materials bear out this prediction."

Mr. Morgan described the relationships between the chemical composition and dielectric loss and dielectric constant and interpreted these quantities in terms of the motions of the electrons, atoms, and molecules making up the dielectric. The various kinds of motion are translational, vibrational, and rotational, and the motion of molecules containing electric dipoles influence both dielectric constant and dielectric loss of the material.

Breakdown of Solid and Liquid Insulators. A. von Hippel's paper showed that: "The extrapolation of Paschen's law from gases under normal pressure up to the high densities of solids and liquids would predict the field strength of electric breakdown in these condensed systems 10 to 100 times higher than observed. The main reasons for this discrepancy are the following: in gases of low density the excitation of the electronic system of the particles acts as the important barrier, which stops the acceleration of the electrons before they reach ionizing velocities. With tight packing of the atoms and molecules these excitation levels become practically destroyed and the excitation of vibrations remains as the decisive mechanism of friction. Hence the study of the excitation functions of vibrations is the most important step for the formulation of the theory of electric breakdown in condensed systems. Next, one has to consider changes of the field distribution and of the structure of the matter itself by charged particles. The field emission of the cathode plays a dominating part to lower the breakdown strength of insulators. Fragile material may crack by mechanical stresses, produced by changes of the particles forming the solid. Hence the total phenomenon is often a very complicated one and the simple theory of heat breakdown, widely accepted, seems to be inadequate."

Influence of Gaseous Discharge on Hydrocarbon Oils. "The new and revolutionary solvent-refining processes now rapidly being adopted by the whole oil industry make possible the production of better oils in most respects than was formerly possible," according to L. J. Berberich. "In the application of such oils to the insulation of high-voltage equipment, however, they were found to possess a serious disadvantage. It was discovered that they were vulnerable to attack by the gaseous electric discharges which occur unavoidably in some high-voltage apparatus. Through research it has been discovered that one class of hydrocarbon molecules, known as the aromatics, is particularly resistant to the action of the discharges, and now it has been found that this same class of hydrocarbons when added to the oil in small percentages reduces the formation of gases markedly. Thus again, a bit of knowledge is added which may result in the transmission of electric power more economically and reliably."

Methods of Measuring the Electrical Properties of Solids. "The essential difference from the point of view of measuring technique between solids and liquids is that the former do not in general give perfect electrical contact with metallic electrodes, which results in the presence of 2 large air capacitances in series with the unknown. A simple mathematical analysis shows that the film capacitances can produce serious experimental errors, which are dependent on the average thickness of the air film, the thickness of the sample, and the dielectric constant and conductance of the sample." R. M. Fuoss described several methods of eliminating such errors, using measurements on typical insulating materials as examples.

Electrical and Chemical Studies of Oil Oxidation. "One of the most important types of high-voltage insulation is the combination of oil and paper. During use, this insulation is subjected to elevated temperatures and high electrical stresses, so there are reactions of the various oil constituents among themselves, with traces of oxygen and water remaining in the cable and with the copper conductor and the lead sheath. One attack on this problem has been the investigation of oil oxidation. By the application of solvent refining methods to the oils, and by the addition of several tests to those now in common use, it is hoped that some new light may be shed on the entire problem. J. C. Balsbaugh discussed the relations between oxidation stability, acid formation, power factor, colloidal content, Grignard test, oil source, and refining methods. He further pointed out that many problems concerning the chemical and electrical aspects of this problem are still without any satisfactory explanation.

Dinner Meeting

Following the symposium, which was attended by about 150 guests and members of the subcommittee, a dinner was held for the subcommittee, at which Doctor T. Smith Taylor (M'21) Diehl Manufacturing Company, Elizabethport, N. J., delivered an address on "Plastics for Electrical Insulation." At this dinner, held at the University Club in Rochester, about 80 people were present.

The joint meeting with the American Chemical Society seemed to direct much interest and enthusiasm toward the problems of insulation research. As a result, the subcommittee has received requests to hold similar symposia each year under the auspices of other divisions of the American Chemical Society.

Diederichs, Engineering Dean, Dies. Herman Diederichs, dean of college of engineering at Cornell University, Ithaca, N. Y., died August 31, 1937. Born at Muenchen-Gladbach, Germany, August 12, 1874, he was graduated from Cornell University in 1897 with the degree of mechanical engineer. The following year he became an instructor in experimental engineering at that university, and in 1902 was made assistant professor. Five years later he was appointed professor, and in 1921 became director of the school of mechanical engineering. Since 1936 he had been dean of the college of engineering. He was appointed John E. Sweet professor of engineering in 1928. Dean Diederichs was the author, with others, of several engineering books. He was a member of The American Society of Mechanical Engineers, Society of Automotive Engineers, American Society for Metals, and Verein deutscher Ingenieur; in 1930 he received the Melville Medal of the ASME.

District 9 Award for Branch Paper

Prize for Branch paper in the AIEE North West District (No. 9) for the period from January to June 1937, inclusive, has been awarded to Thomas Y. Merrell and Edward A. Rich, Enrolled Students, for their paper "Investigation of Losses in Single-Phase Induction Motors," which was presented at a meeting of the University of Utah Branch on May 19, 1937. The award was made in accordance with the revision of prize rules recently adopted by action of the AIEE board of directors, by which the prizes for Branch papers are awarded on the basis of the academic year from July 1 to June 30, inclusive. Excerpts of the rules for prize awards were given in the April 1937 issue of ELECTRICAL ENGINEERING, page 492.

Naval Architects to Meet. The Society of Naval Architects and Marine Engineers will hold its 45th annual meeting at the Waldorf-Astoria Hotel, New York, N. Y., on November 18 and 19, 1937. Among the papers to be presented is "Ship Propulsion by the Emmet Mercury Vapor Process," by W. L. R. Emmet (A'93, M'94, HM'33, Edison Medallist '19, past vice-president, member for life). Other papers will discuss such subjects as the burning of fuel oil, fire control, United States Coast Guard cutters, and alloys in shipbuilding.

ASME Elects Officers for 1938. New officers for 1938 of The American Society of Mechanical Engineers were elected on September 28, 1937, and will assume office on December 10, 1937. They are: *President*—H. N. Davis, president, Stevens Institute of Technology, Hoboken, N. J. *Vice-Presidents*—F. O. Hoagland, master mechanic, Pratt and Whitney division, Niles Bement-Pond Company, Hartford, Conn.; B. M. Brigman (M'28) dean, Speed Scientific School, University of Louisville, Ky.; Harte Cooke, mechanical engineer, McIntosh and Seymour Corporation, Auburn, N. Y.; W. H. McBryde, consulting engineer, San Francisco, Calif.; L. W. Wallace, director, division of engineering research, Association of American Railroads, Chicago, Ill. *Managers*—Carl L. Bausch, vice-president, Bausch and Lomb Optical Company, Rochester, N. Y.; S. B. Earle, dean, school of engineering, Clemson Agricultural and Mechanical College, Clemson College, S. C.; F. H. Prouty, partner, Prouty Brothers Engineering Company, Denver, Colo.

Co-operative Educational Program Announced

A co-operative educational enterprise which will link the Westinghouse Electric and Manufacturing Company and the Carnegie Institute of Technology in a new program of undergraduate engineering training was announced recently by President Robert E. Doherty (A'16, M'27) of Carnegie, formerly chairman of the AIEE committee on education. To make this project possible the Westinghouse company has appropriated $200,000 to the Carnegie Institute of Technology.

The new co-operative program, which will go into effect at the beginning of the next school year, will make it possible for a number of students with superior qualifications to take the usual technical courses for a degree at Carnegie, and, during the same period, to get extensive shop and engineering experience and training in the Westinghouse plant. Of the group of students who will be selected to follow the co-operative course, a number, perhaps 10 each year, will receive George Westinghouse scholarships. A George Westinghouse professorship of engineering also will be established, and one of the duties of the holder of this position will be the supervision of the co-operative program.

The program of study will cover 5 years, of which 4 academic years will be spent at Carnegie. The summer months and 2 college semesters, one in the third and one in the fourth year, will be spent at the Westinghouse plant. Of the students selected for the course, those designated as Westinghouse scholars will receive an income of $50 per month during the 5-year training period from the company. Students will pursue courses not only in electrical engineering, but in the other engineering branches as well. Applications for admission to the co-operative program will be received after January 1, 1938.

Standards

Test Code for Polyphase Induction Machines. There is now available an approved edition of the "Test Code for Polyphase Induction Machines." This is the first of the test codes developed by the AIEE to receive formal approval. (The other codes, which are still in preliminary report form, are "Test Code for Transformers," "Test Code for Synchronous Machines," "Test Code for D-C Machines," and "Test Code for Apparatus Noise Measurement.") The purpose of these test codes is to provide in convenient reference form the more generally applicable and accepted methods of conducting and reporting tests of a commercial nature, which apply to the fulfillment of performance guarantees and to acceptance tests. Copies of the approved code, No. 500, can be obtained from AIEE headquarters at 50 cents each, with 50 per cent discount to AIEE members on single copies.

Safety Code for Elevators. In July 1937 the American Standards Association approved the revised fourth edition of the "Safety Code for Elevators, Dumbwaiters, and Escalators." This code of safety standards covers the construction, inspection, maintenance, and operation of elevators, dumbwaiters, escalators, and their hoistways with certain exceptions. This latest edition was prepared by a sectional committee fully representative of the building, manufacturing, insurance, governmental, and other interests. The committee was sponsored by the National Bureau of Standards, the American Institute of Architects, and The American Society of Mechanical Engineers. The code may be obtained through the ASME, 29 West 39th Street, New York, N. Y., at one dollar per copy.

Manual for Inspection of Elevators. In July 1937 the American Standards Association approved as American recommended practice an "Inspectors' Manual for the Inspection of Elevators." This manual is intended to serve as a guide for the general use of elevator inspectors and is based on the requirements of the "Safety Code for Elevators, Dumbwaiters, and Escalators." The manual may be obtained through The American Society of Mechanical Engineers, 29 West 39th Street, New York, N. Y., at 75 cents per copy.

American Engineering Council

AEC Annual Assembly and Conference of Secretaries

The eighteenth annual assembly of the American Engineering Council and the eighth annual conference of secretaries of engineering associations, clubs, councils, institutes, and societies in the United States are scheduled for January 13, 14, and 15, 1938. The meetings are to be held at the Hotel Mayflower in Washington, D. C. Problems of common concern to the engineering and allied technical professions are being considered by the committees, and the programs, which include the all engineers' dinner, are expected to hold unusual interest for all branches of engineering.

AEC Committee on Merit System

A meeting of the committee on the merit system of American Engineering Council was held in New York, N. Y., September 16, 1937, on the call of Chairman R. L. Sackett. There were present A. W. Berresford (A'94, F'14, past-president, member for life), F. L. Bishop, H. H. Henline (A'19, M'26, national secretary), and J. C. Hoyt of the committee and F. M. Feiker (M'34), *ex-officio*. The committee concurred in the idea of devising ways and means of forwarding the merit system by preparing a plan of procedure whereby state and local societies could sponsor the merit system for employment of engineers in states and municipalities as well as to continue to forward, in the public interest, the general desirability of merit as a basis for federal employment.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Synchronous Motor Effects in Induction Machines

To the Editor:

The effects noted by E. E. Dreese in the paper "Synchronous Motor Effects in Induction Machines" (AIEE TRANSACTIONS, July 1930, pages 1033–40) are not very common and, having run across a case of the same trouble, I believe it should be brought to the attention of induction-motor designers.

This case was brought up when several polyphase motors refused to come up to speed satisfactorily on production test. The rating was $^3/_4$ horsepower, 60 cycles, 220 volts, 4 poles, 1,725 rpm, 2 phase. The motors had 36 stator slots and 32 rotor slots, and were of normal design. Upon making careful investigation, it was discovered that the trouble was due to a synchronous cusp at 225 rpm, $^1/_8$ synchronous speed, similar to that described in the paper by Dreese.

Curve *A* of figure 1 shows the speed-torque characteristic of this motor. Curve *B* shows the same motor with the resistance rings turned smaller, and the air gap increased. Curve *C* shows the motor with a new rotor with more skew, but otherwise the same as the rotor of curve *B*.

One of the peculiar characteristics of this type of cusp was very definitely portrayed by these motors. If a motor has an ordinary induction cusp, such as would be shown by a curve similar to the dotted portion of curve *B*, it will not accelerate any load greater than that shown by the minimum torque point of the cusp. The synchronous cusp acts quite differently. If the synchronous goes to zero or negative, the motors seem to accelerate poorly even on light loads, but will usually come up to speed most of the time if several trials are made. If, however, the synchronous does not fall to zero, and has even half full load torque for a minimum value, the motor seems to accelerate very well. In fact, it is almost impossible to detect by ordinary starting and pull-up tests, that anything is wrong with the motor at all. On a number of motors which had a minimum point of 36 ounce-feet torque, all easily passed a minimum pull-up limit of 54 ounce-feet. Yet if the motors were allowed to slow down with a brake load of 38 ounce-feet, and the switch closed again when the speed had dropped very close to 225 rpm, they would all definitely lock in at the cusp, and refuse to accelerate again until the load was reduced to 36 ounce-feet.

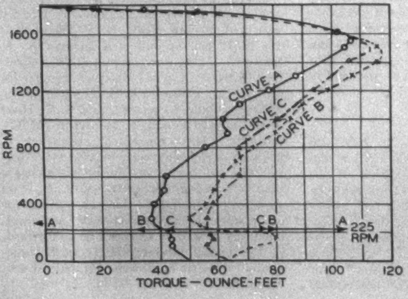


Figure 1. Effect of air gap, skew, and rotor resistance on synchronous cusp of 2-phase motor

Stator slots 36 Rotor slots 32

Curve	Air Gap	Skew	r_2
A	0.020	0.313	2.48
B	0.030	0.313	3.25
C	0.030	0.500	3.25

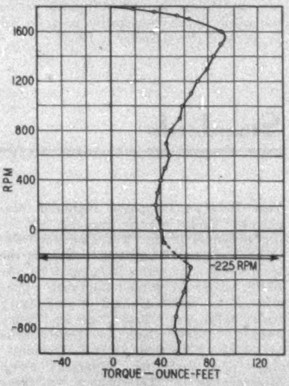


Figure 2. Speed-torque curve of 3-phase motor

Stator slots 36 Rotor slots 32

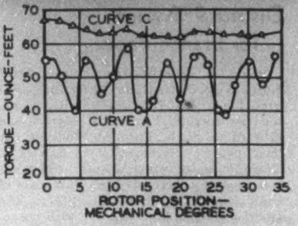


Figure 3. Cogging of 2-phase motor

Stator slots 36 Rotor slots 32

Curve	Air Gap	Skew	r_2
A	0.020	0.313	2.48
C	0.030	0.500	3.25

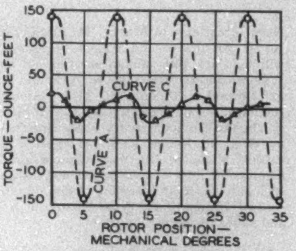


Figure 4. Single-phase cogging of 2-phase motor with one phase open

Stator slots 36 Rotor slots 32

Curve	Air Gap	Skew	r_2
A	0.020	0.313	2.48
C	0.030	0.500	3.25

Upon referring to page 1040 of Dreese's paper, we find that with

$$\frac{N \text{ (rotor slots)}}{p \text{ (poles)}} = \frac{32}{4} = 8$$

table II predicts a cusp at $^1/_{16}$ forward speed, and table III predicts one at $^1/_8$ backward speed, for 3-phase motors. However, upon referring to tables IV and V, for 2-phase motors, we find that $N/p = 8$ does not appear, and no cusp is expected.

On page 1041, C. J. Koch quotes P. L. Alger as finding that cusps would be expected at p/N speed, and would be positive or negative depending on whether the motor were 3 or 2 phase, and whether the rotor or stator had the greater number of lots.

We then tested a similar 3-phase motor, and found a very pronounced cusp at −225 rpm as shown in figure 2. Again I wish to point out that in spite of the magnitude of this cusp, the motor would only lock in when the switch was closed at almost exactly this speed. The motor was loaded with considerable inertia load, and reversed time and time again, passing through the cusp speed quite slowly, and in no case would it lock in except when the switch was closed at just about the correct speed.

The rules of Alger seem to fit these 2 cases, whereas those of Dreese only partially agree. We found the cusp at 1/8 backward speed, but not at 1/16 forward speed, and we did have the 2-phase case.

There was one other curious phenomenon which is illustrated in figures 3 and 4. The cogging or variation of starting torque with rotor position was very noticeable, particularly if one phase was opened. However, the cogging was practically eliminated by the changes which were made in air-gap, rotor resistance, and skew, whereas the synchronous cusp was not.

Very truly yours,
P. H. Trickey (A'30, M'36)
Design Engineer, Diehl Manufacturing Company, Elizabethport, N. J.

Engineering Education and Democracy

To the Editor:

I have read with much interest R. E. Doherty's article entitled "Engineering Education and Democracy," in the September 1937 issue of Electrical Engineering. This impressed me as being one of the most able articles by an engineer that I have read on this very important subject. The author certainly has discovered some of the principal underlying problems and has made some concrete suggestions for a solution.

Such a plan of broadening the education of engineering students and engineers is most commendable and, as he implies, some of our more energetic engineers have acquired something of the type of training, in one way or another, which he has so well described. The constructive point which I would like to raise in connection with the article is: Where are we to get the competent teachers to lead students to this broader outlook?

My own observations are to the effect that comparatively few men in the engineering profession, either in college or out of college, are prepared to furnish the leadership needed to carry forward such a splendid program as Doctor Doherty has outlined. Perhaps it will be necessary to start with the few who are capable as teachers and leaders and gradually develop a force of men trained to furnish this leadership.

All so-called educated people, including the professions, should give thought to the broad economic and governmental problems and it is encouraging to note that an increasing amount of thought and an increasing number of thoughtful articles by engineers are appearing in the various periodicals, and this in itself is a very encouraging sign.

Again expressing my appreciation for this splendid article, I am

Very truly yours,
J. L. Hamilton (M'15, F'21)
Assistant to the General Manager, Century Electric Company, St. Louis, Mo.

To the Editor:

Robert E. Doherty's paper "Engineering Education and Democracy" strikes a responsive cord with me because he so ably has championed a program of engineering education which my colleagues and I have been endeavoring to carry out for more than a quarter of a century. Our program, first proposed and planned by Doctor George E. Hale, has been a great success even though it may be that some of us in our technical subject class rooms have failed to stress sufficiently the human side of engineering. Also, as I read Doctor Doherty's paper, I have been brought to realize that we, along with all others engaged in engineering, have been a bit slow in anticipating the need on the part of engineers for giving more "thought to consequences" which come about as a result of the technical development which has been so great during the last 1 or 2 generations. Indeed, I quite agree with President Doherty that, unless we are careful, there will be reason to become less optimistic about the outcome, for it is high time that we all gave heed to the idea conveyed by a statement which, more than 20 years ago, I once heard made by Doctor J. A. L. Waddell. The statement to which I refer is: "It is not difficult for me to find men who know how to build bridges, but it is tremendously difficult for me to find men who are able to determine whether or not the bridge should be built."

Referring, for purposes of illustration, to the sentence just quoted: As engineers we naturally, in trying to determine "whether the bridge should be built," apply first the laws of economics to see how the cost of the bridge may be paid. During the bad business period through which we have just been passing, we have learned that many persons use factors other than the rules of technical feasibility and economic value to arrive at a decision as to whether an engineering project shall be carried out.

In considering Doctor Doherty's comments concerning the balance between technical subjects content and humanities content in engineering course curricula, I am prompted to recall a striking incident in my own experience which, briefly summed up, resulted in the discovery of a mountaineer with eyes and hands so skillful that he was able to hew a true timber about 8 feet long and 3 by 4 inches in cross section, without the use of any tools other than an adz and an axe. Quite a contrast to the all-too-frequently-employed craftsman who comes with a trunk full of tools and can't turn out a true-surfaced board with square corners.

Good engineering is the measure of the man and not the measure of the number of tools in his kit. My 27 years of teaching experience makes me think that, on the whole, the man with a 4-year engineering course comprising a lot of what we have called the humanities (At California Institute of Technology 20 per cent of a student's time throughout the 4-year course and during the fifth year when the student is working toward the master's degree, is allotted to the study of what we call the humanities.) and which President Doherty has designated as the "social stem" is better prepared for life at the end of his college course than is the man who has given practically all his time during his 4-year college course to the study of technical subjects and to increased specialization. In fact I think such a course as has been described is the ideal education for any citizen of today whether he plans to be an engineer, a business man, or is preparing to engage in some other profession than engineering, such, for example, as the law, medicine, or the ministry. Curricula of this type naturally compel the prospective engineer to acquire most of his professional education after the regular 4-year college course has been completed; and I quite agree with Doctor Doherty that, for the majority of engineers, this follow-up professional education should be obtained in industry rather than by continuation in college. Such a conclusion, of course, is based on the assumption that industry will provide channels through which the student, as he works at being a junior engineer, can obtain the added education needed to make him, in his more mature years, a competent engineer.

Doctor Doherty's 6 phases of education are excellent, but I think there should be an addition to the list of subjects given under number one, making that statement read, "a clear historical understanding of the parallel growths of religion and philosophy, of science and of engineering; because we should not forget that the primary value of a man in the engineering field, as in any other field of endeavor, is determined by that man's ability to live a righteous life whereby he may know how to use correctly the Golden Rule in all his relations with his fellow men." The educational program in which I have had a part has accomplished well the task of teaching all the 6 phases mentioned by Doherty, unless it be number 4, for I must admit that somehow no key has yet been found whereby the teacher may enable every student in his classes to use the English language effectively.

Near the end of his article Doherty has said that a program such as he has suggested may be considered by some as too expensive. Comparatively speaking, such a program is expensive if desired results are obtained, because the 6 points of a rounded education such as he has outlined can be effectively made a part of a student's life only by having the students come in close contact with men of real ability who themselves are examples of what proficiency in those 6 points can do. To do this there must be many teachers and small classes. Young men who have an interest in technical matters and plan to be engineers can be interested in literature and kindred subjects but the teachers of those subjects must be men of outstanding achievement who are inspired with enthusiasm for the subjects which they teach.

Doctor Doherty has concluded his paper with this question: "For what is to be gained by preparing engineers to continue their building of a physically magnificent structure only to have it torn down ultimately by the uncontrolled, unintelligent forces of selfish interests and vandalism?" I should like to supplement that question by another: Is it not the first duty of the engineer as a citizen of his country to make his first question regarding any project be "What does the construction of this project mean to the future of America when considered in the light of its whole influence upon us, our children, and our children's children?" If the answer to that question is satisfactory, then, and only then, has the engineer a moral right to proceed with the design and construction of the project.

Very truly yours,
Royal W. Sorensen
(A'07, F'19, director)
Professor of Electrical Engineering, California Institute of Technology, Pasadena

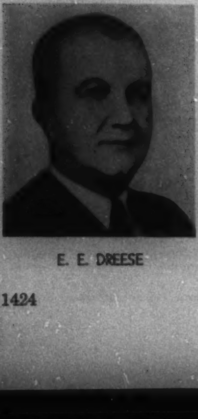
Personal Items

E. E. Dreese (M'25) professor of electrical engineering and chairman of the electrical engineering department of The Ohio State University, Columbus, has been appointed chairman of the Institute's committee on basic sciences for the year 1937–38. Professor Dreese was born at Edmore, Mich., September 10, 1895, and was graduated from the University of Michigan in 1920 with the degree of bachelor of science in electrical engineering. In the following year he was appointed to the electrical engineering faculty of the University of Michigan as an instructor. At the same time he enrolled in the graduate school and in 1925 received the degree of master of science in electrical engineering, following which he was appointed chief engineer of the Lincoln Electric Company, Cleveland, Ohio. Professor Dreese remained with that company for 5 years, and during that time received the honorary degree of electrical engineer from the University of Michigan. In 1930 he was appointed professor of electrical engineering at The Ohio State University and made chairman of the department of electrical engineering. He is an active participant in the local affairs of the AIEE Columbus Section, and has been secretary (1933–34) and chairman (1934–35) of that Section; moreover, for the last 2 years he has been active in committee work of the Institute. He has been a member of the committee on basic sciences (formerly electrophysics) since 1935, and is entering his second year of service on the committees on education and student Branches. Professor Dreese is the author of 2 papers presented before the Institute. He is a member of the Society for the Promotion of Engineering Education, Tau Beta Pi, Eta Kappa Nu, and Sigma Xi.

Wills Maclachlan (A'08, F'21, past vice-president) consulting electrical engineer, Toronto, Ont., Canada, has been appointed to serve as chairman of the Institute's committee on safety for the term 1937–38. Mr. Maclachlan was born August 3, 1885, in Toronto, and received the degree of bachelor of applied science at the University of Toronto in 1907. For one year following his graduation he was employed by the Canadian Westinghouse Company as erection engineer before becoming electrical superintendent of the Dominion Government Grain Elevator at Port Colborne, Ont. After serving other companies in various positions from 1910 until 1913, he was appointed engineer-in-charge of the Electric Power Company, Toronto, in the latter year, and remained in that capacity until 1915, when he became inspector for the Electrical Employers Association of Ontario. Mr. Maclachlan's work for that association has been continuous, and has been concerned with accident prevention in several private and municipal utility companies. Since 1917 he has been consultant on employee relations to the Hydro Electric Power Commission of Ontario and has served as Safety adviser to several other organizations in Ontario. Mr. Maclachlan was vice-president of the Institute during 1919–20, served as a member of the committees on mines (now applications to mining work), 1919–20, and law (now constitution and by-laws), 1920–21. He has been a member of the committee on safety since 1920, and during 1920–21 was a member of the special committee on geographical division and election procedure. Mr. Maclachlan has been active in the committee and administrative work of other organizations, including the former National Electric Light Association, Edison Electric Institute, National Safety Council, Canadian Engineering Standards Association, Canadian Electrical Association, Royal Canadian Institute, and others, and is the author of many papers and articles dealing principally with electric shock and remedial measures.

A. M. MacCutcheon (A'12, F'26, junior past-president) engineering vice-president of the Reliance Electric & Engineering Company, Cleveland, Ohio, has been appointed chairman of the Institute's committee on Institute policy for the term 1937–38. Mr. MacCutcheon was born at Stockport, N. Y., December 31, 1881, and was graduated from the State Normal College at Albany in 1901. After teaching mathematics and science in high schools until 1904 he entered the electrical engineering school at Columbia University and was graduated in 1908. From 1909 until 1914 he was affiliated with the Crocker-Wheeler Company, Ampere, N. J. In 1914 he took charge of all new design work of the Reliance Electric & Engineering Company, was appointed chief engineer in 1917, and in the fall of that year entered the United States Navy. Following his release in 1919 he returned to his former position, and in the following year was elected a director of the Reliance company. Since 1923 Mr. MacCutcheon has held the position of vice-president in charge of engineering. He was a director of the Institute from 1928 until 1932, president during 1936–37, and has served as a member of the following committees: general power applications, 1916–18, 1924–33 (chairman 1925–28); electrical machinery, 1924–34; meetings and papers (now technical program) 1925–29; electric welding, 1928–30; applications to iron and steel production, 1928–33; Edison Medal, 1929–31; executive, 1930–31; standards, 1922–36 (chairman 1931–34) and Lamme Medal, 1934–37 (chairman 1935–36). He is now a member of the executive committee and the Edison Medal committee, and is the Institute's representative on the United States National Committee of the International Electrotechnical Commission, the electrical standards committee of the American Standards Association, the standards council of the same organization, and the John Fritz Medal board of award. Mr. MacCutcheon is a member of several technical and engineering organizations.

W. M. Young (A'24, M'34) formerly research engineer for the Taylor Instrument Companies, Rochester, N. Y., has been appointed dean of the college of applied science of Ohio University, Athens. Doctor Young was born August 17, 1898, at Omaha, Nebr., and received the degrees of bachelor of science in electrical engineering (1921), master of science in electrical engineering (1922), and doctor of philosophy (1926) at the University of Illinois. Following his graduation in 1921 he was appointed assistant in the physics department of the University of Illinois, where he taught electrical measurements until he had completed his graduate studies. In 1926 he was appointed to the faculty of the Texas Technologic College, Lubbock, as adjunct professor of general and engineering physics, but in the following year was transferred to the electrical engineering department as associate professor. Doctor Young became associate professor of electrical engineering at the University of Iowa in 1930; however, he remained there only one year before leaving the teaching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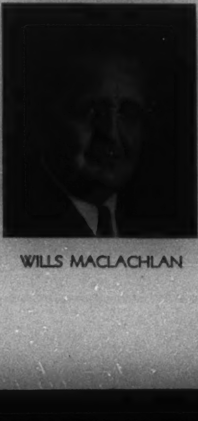
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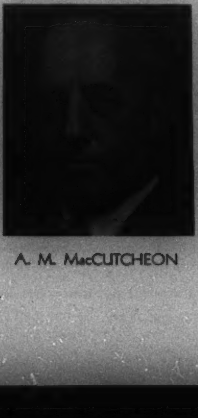
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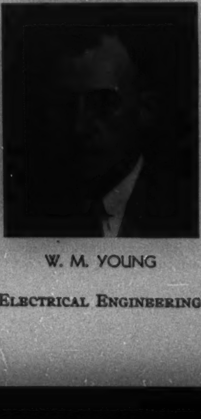

W. M. YOUNG

Stein, Milwaukee

W. E. CRAWFORD

E. S. LEE

E. L. PHILLIPS

ROBIN BEACH

profession to become a research engineer for the Taylor Instrument Companies, in which capacity he has been engaged in the derivation of electrical control instruments for application to industrial processes. He has made numerous contributions of articles and papers to technical and professional journals, and is a member of the American Physical Society, Society for the Promotion of Engineering Education, Tau Beta Pi, Sigma Xi, and Eta Kappa Nu.

Robin Beach (A'15, F'35) professor and head of the department of electrical engineering, Polytechnic Institute of Brooklyn, Brooklyn, N. Y., has been appointed chairman of the Institute's committee on production and application of light for the year 1937–38. Professor Beach was born at Robin's Island, N. Y., August 30, 1889, and received the degrees of bachelor of science in electrical engineering (1913) and electrical engineer (1922) at New Hampshire University. In 1922 he received also the degree of master of science at New York University. Following his graduation in 1913 he served briefly as an instructor in engineering drawing and descriptive geometry at the University of Illinois, but in 1914 became assistant professor of electrical engineering at the Texas Agricultural and Mechanical College and was placed in charge of the development of an electrical measurements laboratory at that school. In 1917 Professor Beach was appointed head of the department of electrical engineering at Norwich University, Norwich, Vt., but remained there for only one year before being appointed to the electrical engineering faculty of the Brooklyn Polytechnic Institute as associate professor. In 1927 he received his full professorship, and in 1930 was appointed head of the department. He has been a member of the Institute's committees on education and production and application of light since 1935 and previously served on the latter committee during 1933–34. He is Institute representative on the United States National Committee of the International Commission on Illumination. Professor Beach is a member of the Society for the Promotion of Engineering Education.

E. L. Phillips (A'26) has retired from the presidency of the Long Island Lighting Company, New York, N. Y., to become chairman of the board of the company. Mr. Phillips was born at Naples, N. Y., March 1, 1873, and was graduated from Cornell University in 1895 with the degree of mechanical engineer, following which he entered the employ of the DeLaval Separator Company as a draftsman. In the following year he transferred his affiliation to the Sprague Electric Company, where he served in a similar capacity as draftsman and designer. Mr. Phillips became associated with Westinghouse, Church, Kerr, and Company, a consulting engineering firm in New York, as engineer in charge in 1897. He remained with that organization for 8 years until he established his own consulting engineering firm in 1905 under the name of E. L. Phillips and Company, with headquarters in New York. For many years he conducted a consulting and contracting business in New York and devoted much of his activity to the construction, expansion, and operation of public utility companies. Mr. Phillips was one of the founders of the Long Island Lighting Company in 1911 and held the position of president of that company for more than 25 years; however, at various times he served as president of the Empire Power Corporation and the Kings County Lighting Company and as chairman of the board of Queens Borough Gas and Electric Company, United Gas and Electric Corporation, and United Gas Engineering Company. He is a member of The American Society of Mechanical Engineers.

E. S. Lee (A'20, F'30, past director) engineer in charge of the general engineering laboratory, General Electric Company, Schenectady, N. Y., has been appointed chairman of the Institute's committee on transfers for the year 1937–38. Mr. Lee, who was born at Chicago, Ill., November 19, 1891, was graduated from the University of Illinois in 1913. He then became an instructor in electrical engineering at Union College and there earned the degree of master of science in electrical engineering, which he received in 1915. Since 1918 he has been affiliated continuously with the General Electric Company, becoming assistant engineer of the general engineering laboratory in 1928 and being appointed to his present position in 1931. Mr. Lee, a past chairman of the AIEE Schenectady Section, has served on many of the Institute's committees: finance, 1933–37 (chairman 1936–37); co-ordination of Institute activities, 1930–33, 1936–37; headquarters, 1936–37; and executive, 1933–37. He has been a member of the committee on instruments and measurements since 1927 (chairman 1927–30) and of the membership committee (chairman 1933–36) since 1933. He has served as Institute representative for the division of engineering and industrial research of the National Research Council, and was director of the Institute from 1933 until 1937. Mr. Lee is the author of numerous technical papers. He has been active in committee work of The American Society of Mechanical Engineers, American Society for Testing Materials, and American Standards Association.

W. E. Crawford (M'28, F'36) consulting engineer, A. O. Smith Corporation, Milwaukee, Wis., has been appointed chairman of the Institute's committee on electric welding for the year 1937–38. Mr. Crawford was born August 21, 1889, at Big Rapids, Mich., and was graduated from the University of Michigan in 1914 with the degree of bachelor of science in electrical engineering. From 1911 until 1917 he taught physics in Michigan high schools, but in 1914 undertook electrical and power survey work for the German American Sugar Company, Bay City, Mich., concurrently with his teaching activities. After serving briefly as assistant chief engineer of the Republic Truck Company, Mr. Crawford became chief engineer of works of the Duplex Truck Company, Lansing, Mich., and remained in that capacity until 1919, when he became consulting engineer to the Mitchell Motors Company. One year later he became plant engineer for the A. O. Smith Corporation; in 1926 he was appointed consulting engineer to that organization and has been retained in that capacity continuously. He has been a member of the Institute's committee on electric welding since 1933. He is a member and past-president of the Milwaukee Welding Society and a member of the American Welding Society.

C. P. Randolph (M'17) chief engineer of the Edison General Electric Appliance Company, Inc., Chicago, Ill., has been elected vice-president of the company. Mr. Randolph was born at Austin, Texas, December 30, 1888, and received the degrees of bachelor of arts (1908) and master of arts (1909) at the University of Texas. In 1909 he enrolled in the graduate school of Massachusetts Institute of Technology, and in the following year was appointed a research associate in chemical engineering. During 1911–12 he was an assistant to William Stanley

(A'87, M'98, F'13, Edison Medalist'12, past vice-president) in evolving electric heating apparatus for the General Electric Company, Pittsfield, Mass., following which he was placed in charge of experimental work on heating devices and later made managing engineer of the heating device department of that company. When the heating device department of the General Electric Company was consolidated with the Hughes Electric Heating Company and the Hotpoint Company to form the Edison General Electric Appliance Company, Inc., in 1928, Mr. Randolph went to Chicago to become chief engineer of the new company.

C. P. RANDOLPH

J. B. THOMAS

R. L. KINGSLAND

R. L. Kingsland (M'14) electrical engineer, Consolidation Coal Company, Inc., Fairmont, W. Va., has been appointed chairman of the Institute's committee on applications to mining work for the year 1937–38. Born May 15, 1882, at Nutley, N. J., Mr. Kingsland was graduated from Cornell University in 1905, and immediately after graduation entered the employ of the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., as an engineering apprentice. In 1907 he was transferred to the turbine testing department of the Westinghouse company, but later in the same year became superintendent of motive power of the Pittsburgh and Butler Street Railway Company. From 1908 until 1909 Mr. Kingsland again served the Westinghouse company in several positions, until he became electrical engineer for the Consolidation Coal Company. His affiliation with that company has been continuous since 1909, during which time he has been assistant superintendent of the power and mechanical department, superintendent of the power and mechanical department, and electrical engineer. Mr. Kingsland has been a member of the Institute's committee on applications to mining work since 1916, and served on the committee on protective devices from 1927 until 1929.

R. D. McManigal (A'18) assistant department manager of the Westinghouse Electric International Company, New York, N. Y., recently was appointed manager of the central station and transportation division of the company. Mr. McManigal joined the Westinghouse company in 1915 after graduation from Lafayette College with a degree in electrical engineering. After completing the company's student training course he was transferred to the general engineering department, where he remained for 7 years, with the exception of a period of service in the United States Navy during the World War. In 1922 he went to Japan as railway specialist for the Westinghouse Electric International Company, and later became managing director of the Westinghouse Electric Company of Japan. In 1931 he returned to the United States to become assistant department manager.

J. B. Thomas (M'28) vice-president of the Texas Electric Service Company, Fort Worth, has been appointed chairman of the Institute's committee on legislation affecting the engineering profession for the term 1937–38. Mr. Thomas was born July 19, 1891, at San Marcos, Texas, and received the degree of bachelor of science in mechanical engineering at the Texas Agricultural and Mechanical College in 1911, following which he held various positions for brief periods before becoming affiliated with the Texas Power and Light Company, Dallas, first as a draftsman and later as an office engineer. During the World War he served in the United States Army Coast Artillery Corps, and at the end of the War returned to the Texas Power and Light Company as resident engineer in 1919; later he became office engineer and assistant chief engineer before being appointed chief engineer of that company in 1921. Mr. Thomas became vice-president of the Texas Electric Service Company in 1930. He has been a member of the Institute's committee on legislation affecting the engineering profession since 1931 and is at present a member of the committee on general power applications. He was a member of the special committee on the engineering profession during 1930–31. Mr. Thomas is a member of The American Society of Mechanical Engineers.

Sidney Hosmer (A'97, F'12, member for life) vice-president and general manager of the Edison Electric Illuminating Company of Boston (Mass.), has retired from active service. He was born July 13, 1871 in London, England, and after being graduated from Yale University in 1892 entered the employ of the Mather Electric Company, Manchester, Conn. In 1894 he was made superintendent of the underground cable department of the Boston Electric Light Company, and when that company was merged with the Edison Electric Illuminating Company of Boston, Mr. Hosmer was made superintendent of construction. He was elected a vice-president in 1926 and in 1932 became general manager and a director.

B. M. Brigman (M'28) dean of the Speed Scientific School, University of Louisville (Ky.), recently was elected a vice-president of The American Society of Mechanical Engineers for the year 1937–38. Dean Brigman, born February 25, 1881, at Louisville, attended the University of Kentucky, received the degrees of bachelor of science (1908) and master of science (1912) at the University of Louisville, and studied in the graduate school of the University of Wisconsin. After teaching in Louisville high schools for several years, he joined the teaching staff of the University of Louisville in 1912, where he has remained since. In 1923 he organized the Speed Scientific School of that institution and was made its dean, a position he has held continuously.

A. A. Atkinson (A'07, M'27) dean of the college of applied science and professor of electrical engineering and physics at Ohio University, Athens, since 1893, has retired. Dean Atkinson was born March 7, 1867, at Nelsonville, Ohio, and received the degree of bachelor of science at Ohio University in 1892. Following one year of graduate study (1892–93) at the University of Michigan he returned to Ohio University and received the degree of master of science in 1895 while serving on the faculty of that institution as associate professor of physics. He is a member of the American Association for the Advancement of Science and the American Physical Society.

E. W. Kimbark (A'27, M'35) formerly an assistant in electrical engineering at Massachusetts Institute of Technology, Cambridge, now is assistant professor of electrical engineering at the Polytechnic Institute of Brooklyn, Brooklyn, N. Y. Professor Kimbark is a native (1902) of Chicago, Ill., and received the degrees of bachelor of science (1924) and electrical engineer (1925) at Northwestern University, following which he entered the graduate school of Massachusetts Institute of Technology and obtained the degree of master of science in electrical engineering in 1933. He was appointed to the staff of that institution in the following year.

W. H. Geiger (A'12) assistant superintendent of the Bergen division, Public Service Electric and Gas Company, Hackensack, N. J., has been promoted to superintendent of that division. Mr. Geiger, a native (1881) of Brumfieldville, Pa., was graduated from the Keystone State Normal School of Pennsylvania in 1904 and from Lehigh University in 1908. Immediately after his graduation in 1908 he became affiliated with the Public Service Electric and Gas Company, where he has spent his entire professional career. He was assistant superintendent of the Bergen division for 18 years.

C. L. Dudley (A'23, M'29) assistant distribution engineer in the electrical distribution department of the Public Service Electric and Gas Company, Newark, N. J., has been made southern division superintendent of that company's electrical distribution department, with headquarters at Trenton, N. J. Mr. Dudley was born at North Branford, Conn., in 1899, and is an electrical engineering graduate of Yale University. He has served in the distribution department of the Public Service company for more than 17 years.

Victor Siegfried (A'32) instructor in electrical engineering at Worcester Polytechnic Institute, Worcester, Mass., has been made assistant professor of electrical engineering. Professor Siegfried, a native (1909) of Seattle, Wash., and an electrical engineering graduate of Stanford University, has been on the teaching staff of Worcester Polytechnic Institute since 1933. He is author or co-author of several papers presented before the AIEE, the latest of which appeared in the October 1937 issue of Electrical Engineering, pages 1285–9.

T. Y. Merrell (Enrolled Student) has received the AIEE North West District prize for Branch paper with E. A. Rich (Enrolled Student) for their paper "Investigation of Losses in Single-phase Induction Motors," presented at a meeting of the University of Utah Branch, May 19, 1937. Mr. Merrell was born December 27, 1914, at Brigham City, Utah, and received the degree of bachelor of science at the University of Utah in 1937.

L. H. Fox (A'31, M'36) who has been associate professor of electrical engineering at Mississippi State College, State College, Miss., now is a member of the development department of Ward Leonard Electric Company, Mount Vernon, N.Y. A native of Fox, Miss., he is an electrical engineering graduate of Mississippi State College and Massachusetts Institute of Technology, and has been a member of the faculty of the former institution since 1930. He is a member of Tau Beta Pi and the Society for the Promotion of Engineering Education.

C. C. Long (A'14, M'30) until recently mechanical and electrical construction engineer, Riegos y Fuerza del Ebro, Barcelona, Spain, now is senior electrical engineer of the Metropolitan Water District of Southern California, Los Angeles. Mr. Long previously was in Spain (1920–22), following which he was an electrical engineer in the department of engineering design of the Southern California Edison Company, Los Angeles, until 1930.

C. L. Chatham (A'25, M'32) electrical distribution department, Public Service Electric and Gas Company, Newark, N. J., has been made assistant distribution engineer. He is a graduate of Massachusetts Institute of Technology and has been with the Public Service company since 1922. Upon completion of a cadet engineering course he was assigned to the Passaic (N. J.) division and was transferred to the Newark offices in 1926.

E. A. Rich (Enrolled Student) has received the AIEE North West District prize for Branch paper with T. Y. Merrell (Enrolled Student) for their paper "Investigation of Losses in Single-Phase Induction Motors," presented at a meeting of the University of Utah Branch, May 19, 1937. Mr. Rich was born March 30, 1916, at Salt Lake City, Utah, and received the degree of bachelor of science at the University of Utah in 1937.

T. S. Sloan (A'21, M'33) for the last 9 years manager of the Rome division of the Georgia Power Company, has been appointed to direct company operations in southwestern Georgia. Prior to his affiliation with the Georgia Power Company, Mr. Sloan was associated with the Central Georgia Power Company in various capacities for more than 12 years.

E. A. Childerhose (M'37, F'37) senior engineer, Federal Power Commission, New York, N. Y., has resigned to join the staff of Jackson and Moreland, consulting engineers, Boston, Mass. Mr. Childerhose will be in charge of electrical engineering on new projects coming under the supervision of that company.

W. F. Jacob (A'35) librarian of the General Electric Company, Schenectady, N. Y., and a former member of the Engineering Societies Library staff, recently was elected president of The Special Libraries Association. He served that organization previously as vice-president.

C. L. Collens (A'07) president of the Reliance Electric & Engineering Company, Cleveland, Ohio, has been elected to membership on the board of directors of the American Standards Association. Mr. Collens is active in the work of the National Electrical Manufacturers Association also.

J. S. Johnson (A'37) instructor in the department of theoretical and applied mechanics at Iowa State College, Ames, who received the degree of doctor of philosophy at that school recently, has become an instructor in electrical engineering at the Missouri School of Mines and Metallurgy, Rolla.

W. O. Ray (A'35) instructor in electrical engineering at the Texas Agricultural and Mechanical College, College Station, was appointed this fall to the electrical engineering department of the Michigan College of Mining and Technology, Houghton.

R. J. W. Koopman (A'36) who has been an instructor in electrical engineering at Michigan College of Mining and Technology, Houghton, now is a member of the electrical engineering faculty of the University of Kansas, Lawrence.

H. T. Kohlhaas (A'07, M'19) editor of *Electrical Communication*, a publication of the International Telephone and Telegraph Company, New York, N. Y., has been transferred to London, England, where that periodical now is being published.

R. E. Thompson (M'34) formerly mechanical engineer for the Federal Light and Traction Company, New York, N. Y., now holds a similar position with the Albuquerque (N. M.) Gas and Electric Company.

E. J. Poitras (A'33) formerly director of research, Ford Instrument Company, Inc., Long Island City, N. Y., now is employed by the Lombard Governor Corporation, Ashland, Mass.

W. F. Ramsay (A'30) recently was employed as a draftsman for Gibbs & Cox, Inc., marine architects and engineers, New York, N. Y.

E. J. Wheeler (A'35) asistant engineering aide, U.S. Biological Survey, San Antonio, Texas, has been made engineering aide and transferred to Denver, Colo.

W. R. Uffelman (A'34) sales engineer for the Clark Controller Company, Detroit, Mich., has been transferred to the Cleveland, Ohio, offices of that company.

H. F. Tincombe (A'36) has been appointed assistant electrical superintendent of the Canadian Johns-Manville Company, Ltd., Asbestos, Que.

J. H. Anderson (A'36) recently affiliated himself with the Electro-Motive Corporation, LaGrange, Ill., as a junior engineer.

F. P. Weiss (A'36) recently entered the employ of the Carnegie-Illinois Steel Corporation, Gary, Ind., as a test engineer.

W. B. Renton (A'34) recently was appointed resident engineer for the H. J. Heinz Company, at Medina, N. Y.

G. N. Brown (A'36) recently was employed by the Western Electric Company, Chicago, Ill., as an equipment engineer.

Obituary

Henry Wright Fisher (A'95, M'01, F'12, member for life) retired consulting engineer for the General Cable Corporation, Perth Amboy, N. J., died near Asheville, N. C., October 7, 1937. Mr. Fisher was born January 31, 1861, at Youghal, Ireland, and was graduated from Cornell University with the degree of mechanical engineer in the class of 1888. After graduation he held one or 2 minor positions before joining the staff of the Standard Underground Cable Company, remaining with that firm until 1927, when it became a part of the General Cable Corporation and he was retained on the engineering staff of the new organization. He was chief electrical engineer of the Standard Underground Cable Company from 1889 to 1915, manager of the lead cable and rubber works from 1915 to 1923, technical director of electrical engineering from 1923 to 1927, and for one year thereafter with the General Cable Corporation, and consulting engineer from 1928 to 1930, when he retired. Mr. Fisher held patents on several improvements in cable construction and methods of locating faults in underground cables, and during the World War was one of a staff of engineers acting in an advisory capacity to the government. He served the Institute as a member of the committees on standards (1914–22) and power transmission and distribution (1915–19) and was a member of the United States National Committee of the International Electrotechnical Commission from 1919 until 1926. He was a member of the American Society for Testing Materials, American Electrochemical Society, and Sigma Xi.

Kay Axel Christiansen (F'37) chief engineer of the Administration of Danish Posts and Telegraphs, Copenhagen, Denmark, died July 13, 1937. Mr. Christiansen was born May 1, 1891, in Copenhagen, and received his technical education in that city, where he was graduated in 1917 as diploma engineer at the Polytechnic Institute. He entered the communications branch of electrical engineering almost immediately, and from 1919 until 1923 he worked for several telephone companies in the United States. During 1923 he entered the service of the Administration of Danish Posts and Telegraphs and became its chief engineer and head of the radio service in 1926. In that capacity he participated in the activities of the International Telephone Consultative Committee, International Consultative Committee on Radio, and the International Radio Union. In 1931 he was president of the second plenary meeting of the committee on radio at Copenhagen.

Theodore Blackwell Morgan (A'21, M'21) southern division superintendent of the Public Service Electric and Gas Company, Trenton, N. J., died September 25, 1937. Mr. Morgan was born at Morgan, N. J., in 1881, and attended Pratt Institute and the Polytechnic Institute of Brooklyn. In 1899 he entered the employ of the Electrical Testing Laboratories, Harrison, N. J., and in 1902 became a helper in the electrical laboratories of the New York Edison Company, Inc., New York, N. Y. He remained with the latter company until 1907, when he was placed in charge of the electrical laboratories of the Brooklyn (N. Y.) Rapid Transit Company. From 1909 until 1920 Mr. Morgan was associated with the Connecticut Electric Light and Power Company, and held various positions in that company until he was appointed assistant superintendent of the southern division of the Public Service Electric and Gas Company in 1920. He became division superintendent in 1928.

David Coburn Bacon (A'28) building and equipment engineer, Southwestern Bell Telephone Company, Dallas, Texas, died August 22, 1937. Mr. Bacon was born September 22, 1884, at Jaffrey, N. H., and was graduated from Worchester Polytechnic Institute with the degree of bachelor of science in electrical engineering. In 1909 he joined the plant department staff of the American Telephone and Telegraph Company, but 2 years later was transferred to the traffic department of the Southwestern Bell Telephone company. After 9 years in the traffic department he was made building and equipment engineer in the engineering department, a position he held continuously for 17 years.

Lucius Foy Deming (A'11) district engineer for the General Electric Company, Philadelphia, Pa., died recently. Mr. Deming was born February 11, 1876, at Amboy, Ill., and was graduated from Yale University in the class of 1896. He became affiliated with the General Electric Company soon after his graduation and never relinquished his position with that company during more than 40 years of active professional service. His first position was in the testing department of the General Electric Company; later he became a d-c designer, a rotary converter designer, and in 1906 district engineer.

Banka Behari Roy (A'31) power station superintendent, Ahmedabad (India) Electricity Company, Ltd., died several months ago, according to word just received at Institute headquarters. Mr. Roy was born September 14, 1889, at Dakshinpaiksha, India, and attended Calcutta University, following which he received practical training in electrical engineering as a general assistant for the British Engineering Company, Calcutta, and later was employed by several railway companies in India. He became power station superintendent of the Ahmedabad Electricity Company in 1929.

Milton M. Gess (A'34) electrical engineer, Battery Equipment and Supply Company, Chicago, Ill., died August 25, 1937. Mr. Gess was born December 18, 1909, at Dolton, Ill., and was graduated from Armour Institute of Technology with the degree of bachelor of science in electrical engineering in 1929, following which he became a testman, and later electrical engineer for the Battery Equipment and Supply Company.

Membership

Recommended for Transfer

The board of examiners, at its meeting on October 14, 1937, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Member

Conlon, F. B., development engineer, Airtemp Inc., Dayton, Ohio.
Endicott, William, general assistant, General Electric Company, Minneapolis, Minn.
Gaskins, Richard W., electrical engineer, Union Electric Company of Illinois, St. Louis, Mo.
Meyerand, R. G., electrical engineer, Union Electric Company of Missouri, St. Louis.
O'Neill, O., assistant engineer, Consolidated Edison Company of New York, Inc., New York, N. Y.
Parker, L. H., electrical engineer, Turlock Irrigation District, Turlock, Calif.
Polster, M. A., assistant to superintendent, electrical distribution department, Consolidated Gas, Electric Light and Power Company of Baltimore, Baltimore, Md.
Shoffner, J. R., electrical and chief engineer, Allegheny River Mining Company; Reid Coal Company; Ringgold Coal Company; Ringgold Corporation, Timblin, Pa.
Spencer, T. A., member technical staff, Bell Telephone Laboratories, Incorporated, New York, N. Y.
Wolf, H. B., maintenance foreman, Duke Power Company, Charlotte, N. C.

10 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before November 30, 1937 or January 31, 1938, if the applicant resides outside of the United States or Canada.

Abramson, L. Z., Gibbs & Hill, New York, N. Y.
Bailey, R. E., Utah Power & Light Co., Park City, Utah.
Belkin, E. I., 1166 Manor Avenue, New York, N. Y.
Brandenstein, E. W. (Member), General Electric Co., Erie, Pa.
Burnham, R. F., Connecticut Power Company, Stamford, Conn.
Carter, H. E. (Member), Duke Power Co., Charlotte, N. C.
Carter, L. T. (Member), General Electric Company, New York, N. Y.
Cohen, LeR. D., Tennessee Valley Authority, Wilson Dam, Ala.
Dayton, C. S., Jr., Safety Car Heating and Lighting Company, New Haven, Conn.
Deardorff, H. E., Dayton Power and Light Company, Dayton, Ohio.
Dellamano, F. J., Consolidated Edison Company of New York, Inc., New York, N. Y.
Douglass, W. E. (Member), Monongahela West Penn Public Service Company, Wellsburg, W. Va.
Doyle, A. M., Canadian General Electric Company, Toronto, Ont., Canada.
Durbeck, E. F., Jr., Louisville Gas and Electric Company, Louisville, Ky.
Dyer, W. L., Southern California Edison Company, Ltd., Long Beach, Calif.
Enschede, M. H., Pacific Tel. & Tel. Co., Seattle, Washington.
Festner, R. H., New York Telephone Company, New York, N. Y.
Fulmer, J. L., Southern Bell Telephone and Telegraph Company, New Orleans, La.
Funderburg, C. H., Tennessee Valley Authority, Pickwick, Tenn.
Genthner, H. J., Rochester Gas and Electric Corporation, Rochester, N. Y.
Giba, J. J., Arma Engineering Company, Inc., Brooklyn, N. Y.
Giegerich, B. V., General Electric Company, Pittsfield, Mass.
Hagadorn, F. G., General Electric Company, San Francisco, Calif.
Hamilton, H. L., Keystone Pipe Line Company, Philadelphia, Pa.
Havens, M. LeR., 40 Arneys Mount Road, Pemberton, N. J.
Hellmann, R. K., Transatlantic Research and Information Service, Inc., New York, N. Y.
Hickey, W. J., Consolidated Edison Company of New York, Inc., New York, N. Y.
Hollifield, R., Ohio Edison Company, Akron.
Holt, C. B., Jr., Pennsylvania State College, State College, Pa.
Jewett, LeR. R., Gamewell Company, Sacramento, Calif.
Johnson, W. R., Tennessee Valley Authority, Chattanooga, Tenn.
Joyce, T., Union Electric Company of Missouri, St. Louis, Mo.
Kado, Y., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Koch, C. A., Cleveland Railway Company, Cleveland, Ohio.
Kyne, S. B., Connecticut Light and Power Company, Norwich.
Leitch, J. D. (Member), Electric Controller and Manufacturing Company, Cleveland, Ohio.
Lincoln, G. E., Western Union Telegraph Company, New York, N. Y.
Loehr, J. E., Consolidated Edison Company of New York, Inc., New York, N. Y.
Marshall, M. G., Commonwealth and Southern Corporation, New York, Jackson, Mich.
Masters, L., Eisemann Magneto Corporation, Brooklyn, N. Y.
McDonald, D. B., Texas Electric Service Co., Fort Worth, Texas.
McDonald, J. P., Scranton Electric Company, Harding, Pa.
McNamara, F. T., Yale University, New Haven, Conn.
Merwin, G. W., American Telephone and Telegraph Company, New York, N. Y.
Miller, M. C. (Member), Ebasco Services, Inc., New York, N. Y.
Neal, C. W., Oklahoma Gas and Electric Co., Oklahoma City, Okla.
Norberg, H. A., Phillips Petroleum Company, Bartlesville, Okla.

Owen, L. E., Tennessee Valley Authority, Wilson Dam, Ala.

Parks, W. K., Westinghouse Electric & Manufacturing Company, Buffalo, N. Y.

Peabody, A. W., Phoenix Engineering Corporation, New York, N. Y.

Pepperberg, L. E., Republic Steel Corporation, Cleveland, Ohio.

Peterson, J. A., Commonwealth and Southern Corporation, Jackson, Mich.

Putnam, T. R., New York Telephone Company, New York, N. Y.

Raab, C. F., Tennessee Valley Authority, Chattanooga, Tenn.

Rae, F. H., Norma-Hoffmann Bearings Corporation, Stamford, Conn.

Relfe, D. H., Port of Oakland, Oakland, Calif.

Rexroth, B. A., Southwestern Bell Telephone Company, Oklahoma City, Okla.

Rice, J. B., Allis-Chalmers Manufacturing Company, Pittsburgh, Pa.

Salisbury, A. M., Westfield Gas and Electric Department, Westfield, Mass.

Scheffer, S. L., Phoenix Engineering Corporation, New York, N. Y.

Shelton, S. P., Bureau of Power and Light, City of Los Angeles, Calif.

Sherry, R. P., Long Island Lighting Company, Glenwood Landing, N. Y.

Slater, E. A. (Member), Westinghouse Electric & Manufacturing Company, San Francisco, Calif.

Spencer, H. H., Bell Telephone Laboratories, Incorporated, New York, N. Y.

Stanley, W. McC., Tennessee Valley Authority, Wilson Dam, Ala.

Starr, F. C., General Electric Company, Rochester, N. Y.

Stein, G. M. L. (Member), General Electric Company, Pittsfield, Mass.

Stemler, D. R., Pennsylvania Power & Light Company, Allentown, Pa.

Toth, A., International Printing Ink Company, New York, N. Y.

Tratt, F. H., Stromberg-Carlson Telephone Manufacturing Company, Rochester, N. Y.

Vallin, G. L., General Electric Company, Pittsfield, Mass.

Walsh, F. H., Jr., Paul H. Jaehnig, Inc., Newark, N. J.

Watkins, J. H., Jr., General Electric Company, Pittsfield, Mass.

Weaver, C. E., Eastman Kodak Company, Rochester, N. Y.

Woods, C. A., Jr., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

Wright, N. G., Ohio Brass Company, Barberton, Ohio.

Wyatt, C. H., Oklahoma Gas & Electric Co., Oklahoma City, Okla.

Young, C. F., Federal Shipbuilding & Dry Dock Company, Kearny, N. J.

Youngs, F. L., General Electric Company, Pittsfield, Mass.

Zeiner, G. E. (Member), American Telephone and Telegraph Company, New York, N. Y.

80 Domestic

Foreign

Hill, H., in care of Roan Antelope Copper Mines, Luanshya, Northern Rhodesia, Africa.

Laroza, E. E. (Fellow), Escuela de Ingenieros de Lima, Lima, Peru.

Narayan, B., Poona Electric Supply Company, Ltd., Poona, India.

Nethersole, H. J. H. (Member), Trinidad Leaseholds, Ltd., Pointe-a-Pierre, Trinidad, B. W. I.

Preston, W. F., Pernambuco Tramways and Power Company, Ltd., Brazil.

5 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Bodine, Ralph B., 14 N. Ferry, Schenectady, N. Y.

Boissonnault, F. L., 928 W. 8th Place, Los Angeles, Calif.

Charlton, H. C., 4827 Wilson Avenue, Montreal, Que., Canada.

Cooper, Peter G., 50 Stanton St., Schuylkill Haven, Pa.

Dadashev, Musa, 32 Zamkovaja, Ulitsa, Baku, U.S.S.R.

Eakins, William V. G., 45 W. Mohawk St., Buffalo, N. Y.

Fassett, Frank C., 100 Seward Ave., Detroit, Mich.

Gregory, G. A., 1217 Jefferson Street, Olympia, Wash.

Hall, John R., 1464 S. 74th St., West Allis, Wis.

Herr, Melvin D., South 228 Lincoln St., Spokane, Wash.

Kirk, W. C., 216 E. 22nd St., Owensboro, Ky.

Koziol, Roman Joseph, 174 Farmington Ave., Hartford, Conn.

Macomber, George S., Federal Power Commission, Washington, D. C.

Matthews, Robert W., 42 St. Stephen St., Boston, Mass.

McLean, Lee Vance, 1926 North Blvd., Baton Rouge, La.

Rizk, Kaleel S., Co. 418, C.C.C., Olustee, Fla.

Roberts, William N., 4175 Springle, Detroit, Mich.

Tribble, William Harry, 303 Park Place, Brooklyn, N. Y.

Williams, Thomas J. C., 325 Seward Place, Schenectady, N. Y.

19 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

MODERN ELECTRIC and GAS REFRIGERATION. By A. D. Althouse and C. H. Turnquist. Chicago, Goodheart-Willcox Company, 1936. 858 pages, illustrated, 8x5 in., leather, $5.00. A practical textbook for school use and home study.

PHYSICS of ELECTRON TUBES. By L. R. Koller. 2nd edition. New York and London, McGraw-Hill Book Company, 1937. 234 pages, illustrated, 9x6 in., cloth, $3.00. Considers the fundamental physical phenomena of electron tubes, disregarding external circuit conditions. The revision consists of corrections, added topics, and some expansion. Designed to interest technical men having no special training in electronics.

RECOLLECTIONS and REFLECTIONS. By J. J. Thomson. New York, Macmillan Company, 1937. 451 pages, illustrated, 10x6 in., cloth, $4.00. Mainly autobiographical, covering school and college days, first experimental work, visits to various countries, and psychical research. Later chapters contain sketches of contemporaries and lucid descriptions of certain important developments in the field of physics in which Thompson had a part, or which came within his time.

REPORTS on PROGRESS in PHYSICS, volume 3, edited by A. Ferguson. Published by the Physical Society, London, at University Press, Cambridge, 1937. 394 pages, illustrated, 10x7 in., cloth, 20s. Provides a review of the advances in physics during 1935. Among the subjects covered are: general physics, atomic physics, the measurement of noise, magnetism, experimental electricity and magnetism, electrical methods of counting, superconductivity, and the theory of metals, photoelectricity, optics, X rays, and spectroscopy.

SCIENCE MUSEUM. Board of Education. ELECTRIC ILLUMINATION, by W. T. O'Dea. London, His Majesty's Stationery Office, 1936. 40 pages, illustrated, 10x6 in., paper (obtainable from British Library of Information, 270 Madison Ave., New York, $0.20). A brief sketch of the principles, application, and development of electric lighting, prepared for general use by the Science Museum.

TROUBLES of ELECTRICAL EQUIPMENT. By H. E. Stafford. New York and London, McGraw-Hill Book Company, 1937. 330 pages, Illustrated, 9x6 in., cloth, $3.00. A treatment of the ills of electrical equipment from the diagnostic viewpoint. For the practical man.

UNIFORM SYSTEM of ACCOUNTS for ELECTRIC UTILITIES. Edited by National Association of Railroad and Utilities Commissioners. New York, State Law Reporting Company, 1937. 213 pages, tables, 9x6 in., paper, $2.00. Prepared by the committee on statistics and accounts of public utilities, and recommended to the commissions represented in the membership of the Association at the 1936 convention.

WIRELESS SERVICING MANUAL. By W. T. Cocking. 2nd edition. London, Wireless World, Iliffe and Sons, 1936. 231 pages, illustrated, 5s. Devoted entirely to servicing problems; the reader is assumed to have a knowledge of basic principles.

APPLIED GEOPHYSICS, by H. Shaw. London, Science Museum. Publ. by His Majesty's Stationery Office, 1936. 102 p., illus., 10x6 in., paper, 2s. (Obtainable from British Library of Information, 270 Madison Ave., New York, $.65.) Intended as a guide to the exhibit of geophysical apparatus in the Science Museum, London; in addition contains an explanation of the various methods of geophysical surveying.

ELECTROLYTIC CONDENSERS. By P. R. Coursey. London, Chapman & Hall, 1937. 172 p. illus., 9x6 in., cloth, 10s. 6d. A summary of recent developments in the design of electrolytic condensers, together with an account of their properties and uses.

ELEKTROTECHNISCHE ISOLIERSTOFFE, Entwicklung, Gestaltung, Verwendung; Vorträge von H. Burmeister, W. Eitel, W. Estorff, W. Fischer, K. Franz, G. Pfestorf, R. Vieweg, W. Weicker. Ed. by R. Vieweg. Berlin, Julius Springer, 1937. 295 p., illus., 10x6 in., cloth, 19.80 rm. A series of lectures which aimed to give a review of the present development of insulating materials, both scientifically and technically.

INTRODUCTION to FERROMAGNETISM. By F. Bitter. New York and London, McGraw-Hill Book Co., 1937. 314 p., illus., 9x6 in., cloth, $4.00. Defines the problems whose solution may be expected to reveal the fundamental processes which constitute ferromagnetism, and discusses magnetic, mechanical, and electrical phenomena.

ORIGINS of CLERK MAXWELL'S ELECTRIC IDEAS as described in familiar letters to William Thomson. Ed. by Sir Joseph Larmor. Cambridge (England) The University Press; New York, Macmillan Co., 1937. 56 p., illus., 10x7 in., cloth, $1.00. Contains a series of letters written between 1854 and 1879 that present an account of the genesis and rapid progress of Maxwell's ideas.

THEORY of ALTERNATING-CURRENT MACHINERY. By A. S. Langsdorf. New York and London, McGraw-Hill Book Co., 1937. 788 p., illus., 9x6 in., cloth, $6.00. A text for advanced electrical engineering students, giving a comprehensive discussion of all types of electromagnetic machines as well as of the basic principles which influence their design and operating characteristics; quantitative relations are approached through the medium of geometrical representation.

VERSUCHE zur ELEKTRISCHEN RESONANZ mit HOCHFREQUENTEN und NIEDERFREQUENTEN WECHSELSTRÖMEN (Versuche mit kleinen Röhrengeneratoren). (Abhandlungen zur Didaktik und Philosophie der Naturwissenschaft, Heft 16). By F. Moeller. Berlin, Julius Springer, 1937, 1937. 82 p., illus., 11x8 in., paper, 4.80 rm. A guide to numerous experiments in the field of resonance with small vacuum-tube generators.

VORSCHRIFTENBUCH des VERBANDES DEUTSCHER ELEKTROTECHNIKER. Ed. by die Geschäftsstelle des VDE. 21 ed. Berlin, Verband Deutscher Elektrotechniker, 1937. 1414 p., illus., 8x6 in., cloth, 16.20 rm. Contains a complete set of the specifications, rules, and practices for electrical work adopted by the Society of German Electrical Engineers and in force on January 1, 1937.

WHO'S WHO in ENGINEERING, a Biographical Dictionary of the Engineering Profession. Ed. 4, 1937. Ed. by W. S. Downs. New York, Lewis Historical Publishing Co., 1937. 1638 p., 10x6 in., cloth, $10.00. Contains brief professional biographies of 12,000 American engineers.

Engineering Societies Library

29 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a co-operative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Industrial Notes

Federal Power Commission Hearing.—The Federal Power Commission will hold a public hearing on November 15, in Washington, D. C., on the application of the Pacific Gas & Electric Co., San Francisco, for a preliminary permit to construct six major hydroelectric developments on the North Fork of the Feather River, having an aggregate proposed installed capacity of 368,000 kva. The company at present owns and operates the only three hydroelectric plants on the North Fork of the Feather River. These are known as Big Bend, Bucks Creek, and Caribou plants. The six proposed plants are planned to be built between the Caribou plant and the Big Bend plant. The difference in elevation between these two points is 2,072 feet and it is this difference in elevation or head of the river which is to be developed through the proposed construction. On the date of the application, the company is shown as operating 39 hydroelectric plants, two operated under lease, with a total installed capacity of 1,011,285 horsepower and 8 steam plants with a total installed capacity of 426,608 horsepower.

Westinghouse Expands Elevator Plant.—One of the largest and most complete elevator and electric stairway plants in the world is now located in Jersey City, as a consequence of the recent acquisition by the Westinghouse Elevator Co. of the assets of the A. B. See Elevator Co., Inc. With the removal of the Westinghouse company's headquarters from Chicago to Jersey City, plans have gone forward for increasing the manufacturing aisle space at the plant at 150 Pacific Ave., Jersey City, by approximately 50 per cent, and for doubling office space there. The A. B. See Company, third largest in the industry, was founded in 1883 by Alonzo Bertram See, and specialized in apartment house and industrial elevators.

General Electric Orders Rise.—Orders received by the General Electric Co., during the first nine months of this year amounted to $305,276,556, an increase of 44 per cent over the $211,891,038 received during the same time last year. Sales billed during this period amounted to $260,773,533 compared to $189,263,156 during the corresponding period of 1936, an increase of 38 per cent. Orders received during the third quarter this year amounted to $88,010,937 compared with $74,922,441 during the corresponding period last year, an increase of 17 per cent. The third quarter and the first nine months during 1937 were the largest of any similar periods since 1929.

Roller-Smith Appointment.—C. F. Cate, 234 N. Davis St., El Paso, Texas, has been appointed sales agent for the Roller-Smith Co., of New York City, for the southwestern portion of Texas and the southern portion of New Mexico.

U. S. Rubber Appointment.—The mechanical goods division of U. S. Rubber Products, Inc., has announced the appointment of Frederick D. Benz, formerly manager of wire sales, Chicago branch, as district manager of wire sales, Pacific division, with headquarters at San Francisco.

Cutler-Hammer Appointments.—A. R. Johnson has been appointed manager of the merchandising sales division of Cutler-Hammer, Inc., Milwaukee; Elmer F. Weiss is now manager of the Detroit office, succeeding Mr. Johnson; E. T. Rees has been appointed branch sales manager of the office in Indianapolis, and a new branch sales office at Portland, Oregon, has been opened with F. J. Woldrich in charge.

New Thread-Cutting Screw.—The Shakeproof Lock Washer Co., 2501 N. Keeler Ave., Chicago, Ill., has announced the development of a screw that cuts its own thread in metals and plastics of practically any thickness. Its patented, thread-cutting slot, plus a special hardening process, eliminates the separate tapping operation normally required in the use of standard machine screws. Important production savings in both labor costs and time are claimed for use of this new fastening method.

Improved Solenoid Relay.—An improved Durakool mercury switch is now used on type A solenoid relays manufactured by G-M Laboratories, Inc., Chicago. The Durakool switch is of unbreakable construction; the steel shell enclosing the chamber contains mercury and a liquid fill. The liquid fill is a new development which insures maximum initial contact, prevents oxidation, quenches the arc and washes away impurities. The steel enclosure is covered with a Bakelite housing. This type relay has proved particularly suited to operations where an enclosed switch contact is desirable or necessary, such as a refrigerator fan control.

Trade Literature

Millivoltmeters.—Bulletin 480. Describes recording millivoltmeters for electrolysis surveys. Scales and ranges are included. The Bristol Co., Waterbury, Conn.

Oscillograph.—Bulletin, 4 pp. Describes new, type 168, Du Mont all purpose 5-inch cathode-ray oscillograph. Portable, for laboratory or field. Allen B. Du Mont Laboratories, Inc., Upper Montclair, N. J.

Industrial Lighting Equipment.—"Handbook of Localized Lighting," ML6, 16 pp. Describes flexible arm lighting units with various types of reflectors, including indirect canopy types. The Fostoria Pressed Steel Corp., Fostoria, O.

Transformers.—Bulletin (broadside). Illustrates 14 of the various types of transformers of this manufacturer, principally distribution and power equipment. R. E. Uptegraff Manufacturing Co., 300 N. Lexington Ave., Pittsburgh, Pa.

Tree Wire.—Bulletin C-36, 8 pp. Describes Anaconda Duracord tree wire. Includes interesting illustrated tests indicating the reliability of such wires under extreme operating conditions. Insulation thickness tables are also included. Anaconda Wire & Cable Co., 25 Broadway, New York City.

Pin Type Insulators.—Bulletin 30-1918, 4 pp. Describes radio interference proof, high voltage, pin type insulators—the method of applying copper oxide glaze, application of insulators, and methods of testing for radio interference. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

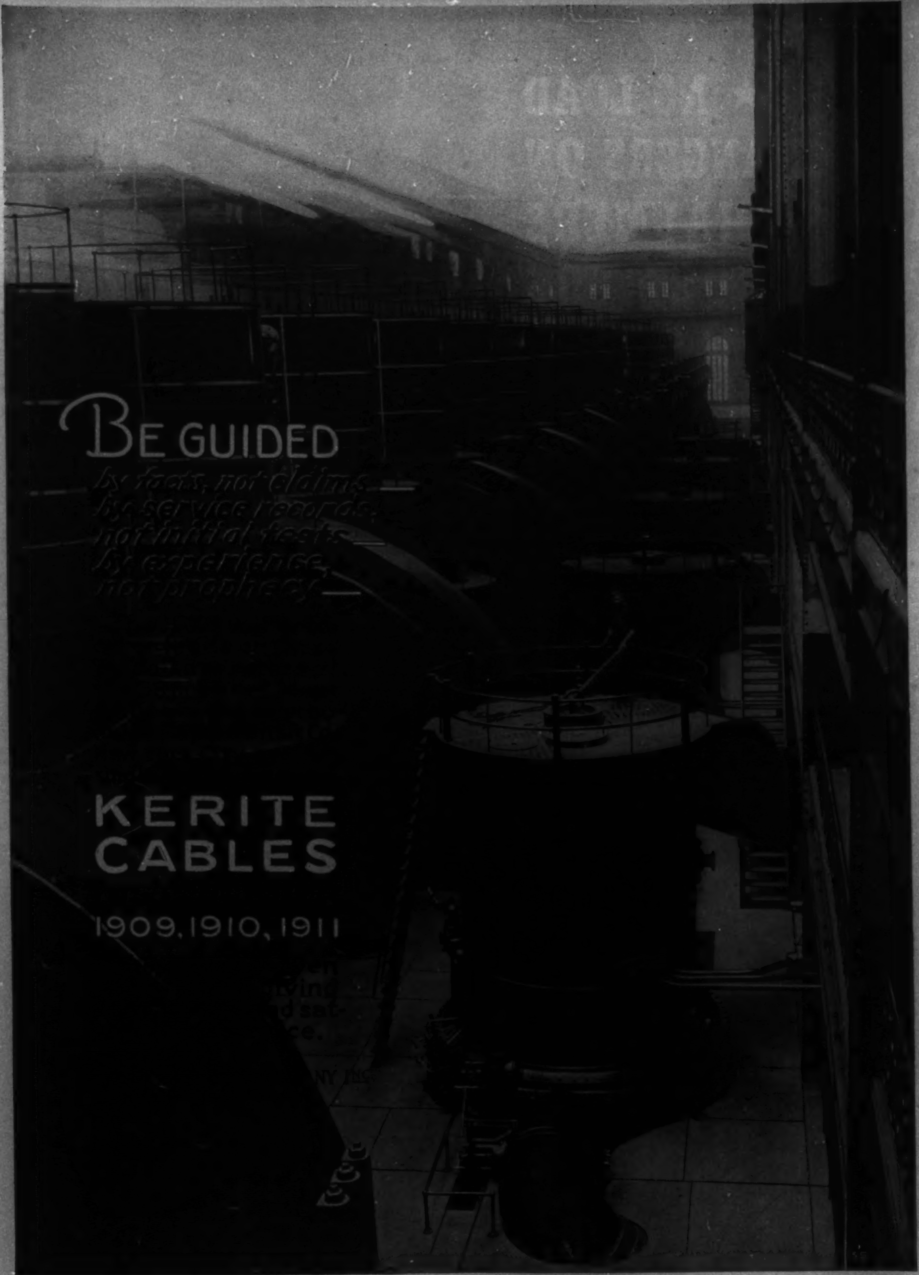
Stiffness Testers.—Bulletin 11, 12 pp. Describes various types of machines for testing stiffness of practically all materials, in every form, as well as many manufactured products used in industry. Methods of tests are outlined in full, and diagrams showing results of typical tests are included. Tinius Olsen Testing Machine Co., 500 N. 12th St., Philadelphia, Pa.

Radio Noise Suppression.—Folder, "Clear Reception," on the subject of background noise suppression. The several ways in which noises reach a receiver and how they may be stopped either at the set itself, or preferably at the noise source, are outlined. Also featured are the several types of noise eliminators or filters. Aerovox Corp., 70 Washington St., Brooklyn, N. Y.

Conduit, Insulating Materials, Etc.—Catalog G1-6A, 64 pp. Includes chapters on asbestos-cement conduit for electrical wires and cables; Asbestos Ebony, used for switchboard panels and other electrical mountings; Transcell for cell structures and doors. Among other products described are built-up and insulated roofs, industrial friction materials, pipe insulations, packings, gaskets, etc. Johns-Manville, 22 E. 40th St., New York City.

Non-Metallic Underground Cable.—Bulletin UC-2, 16 pp. Describes Trenchlay and Ruralay cables for direct earth installation on single phase systems. Summarizes the economic and other advantages of these types of cables for rural application, and illustrates installation and splicing methods. A comparative voltage drop chart for a specific overhead and underground line is included in the bulletin. General Cable Corp., 420 Lexington Ave., New York City.

New Photoelectric Potentiometer.—Bulletin 501-A, 4 pp. Describes Model 721 photoelectric potentiometer and its related equipment. The unique electronic balancing method of the new instrument is outlined, whereby widened application of potentiometric sensitivity to continuous measurement and control of rapidly varying electrical quantities, or other quantities (temperature, light, etc.) may be translated into electrical units. Among the fields of application for the unit, suggested in the bulletin, are pyrometry, electrochemical measurement and control, standardization and regulation of currents, voltages, light values, etc. Weston Electrical Instrument Corp., Newark, N. J.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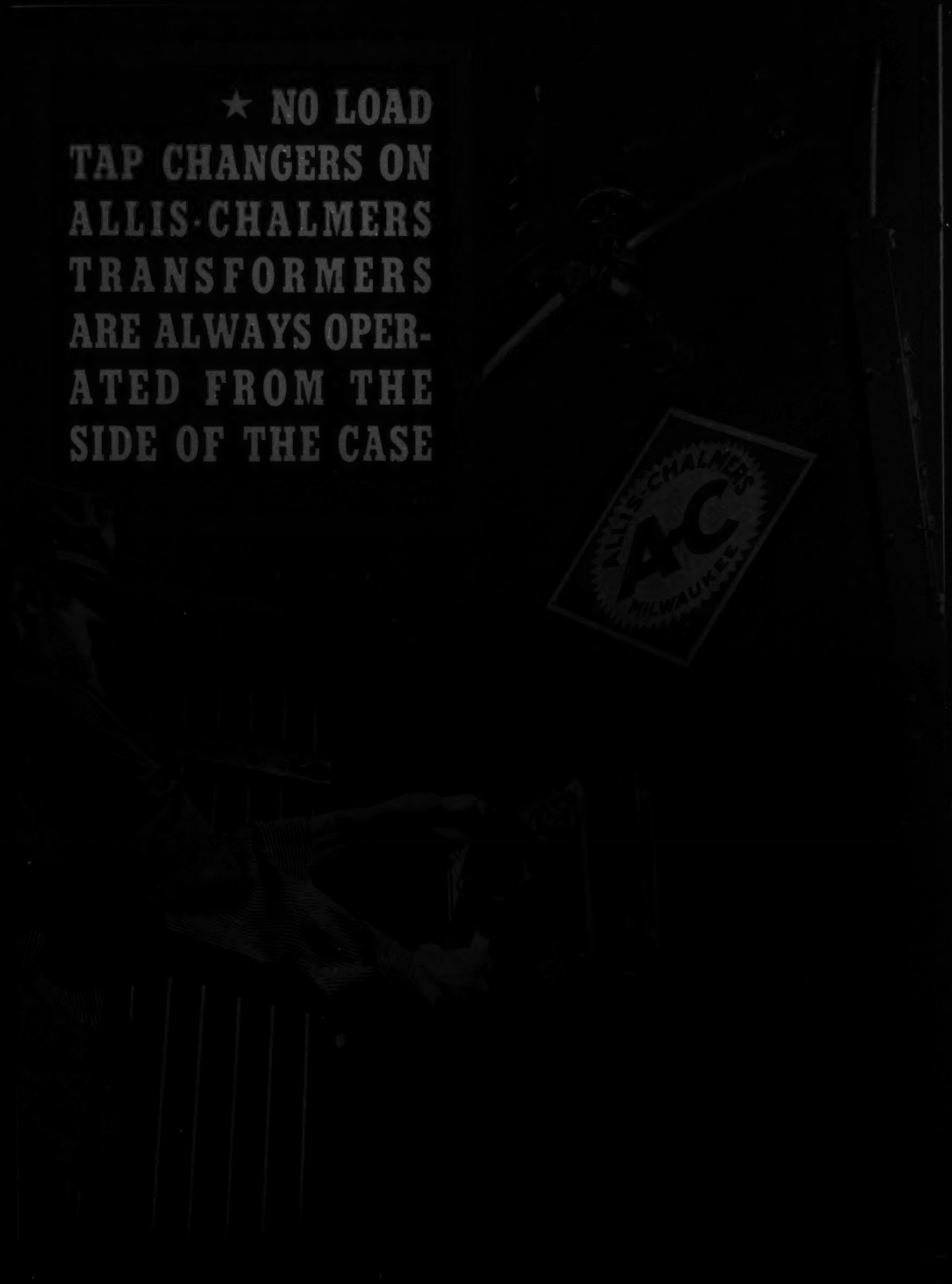

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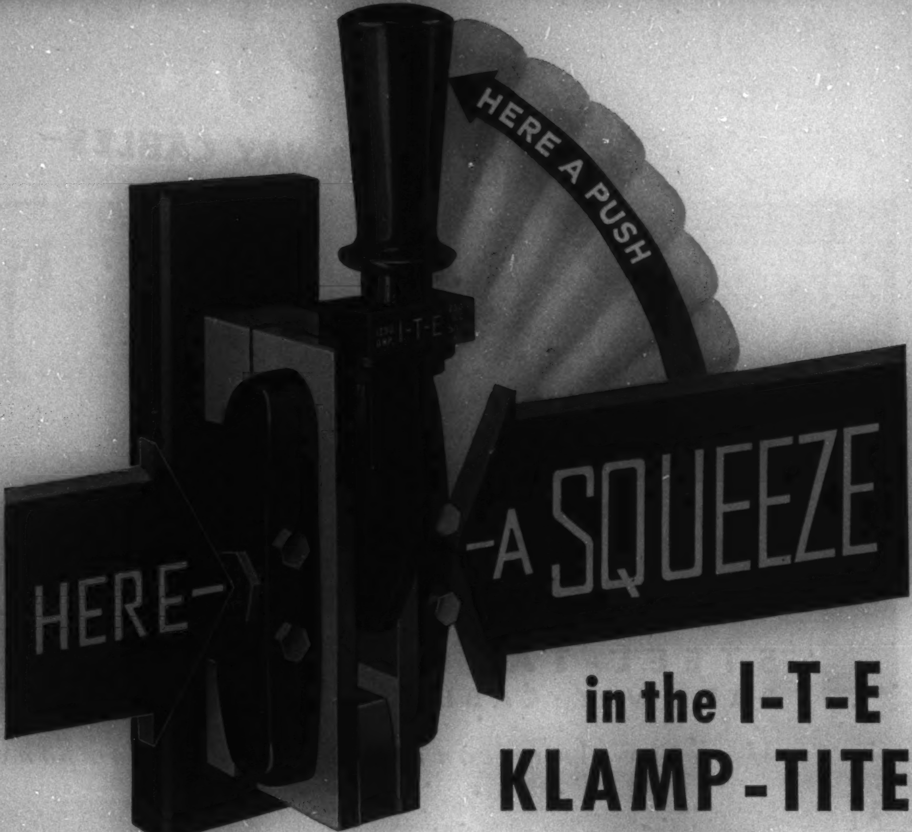

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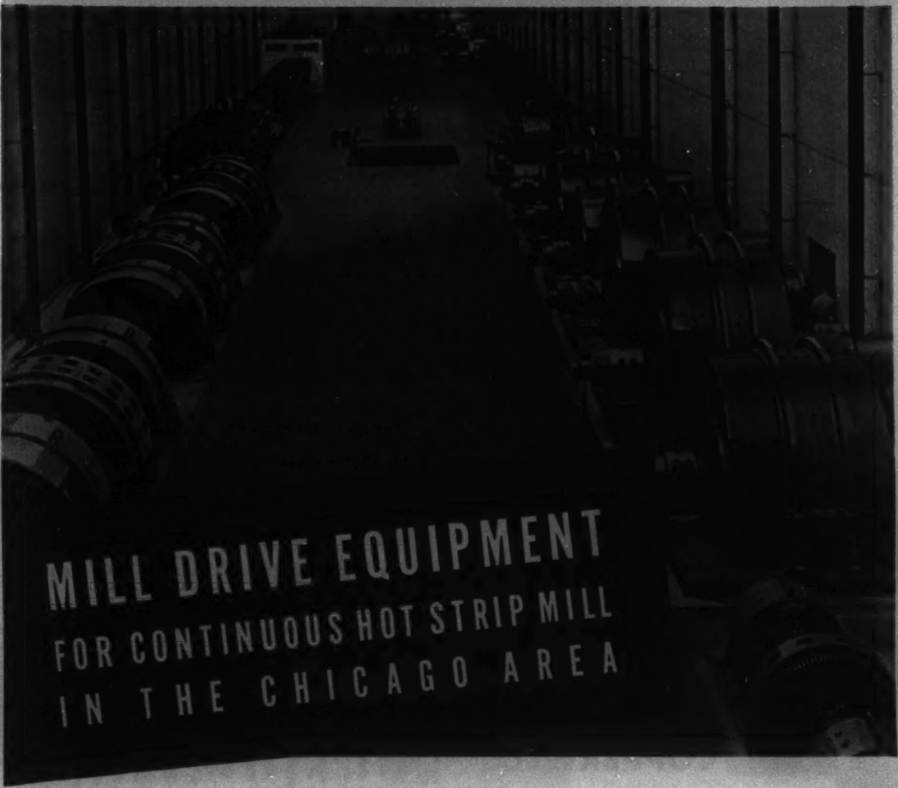

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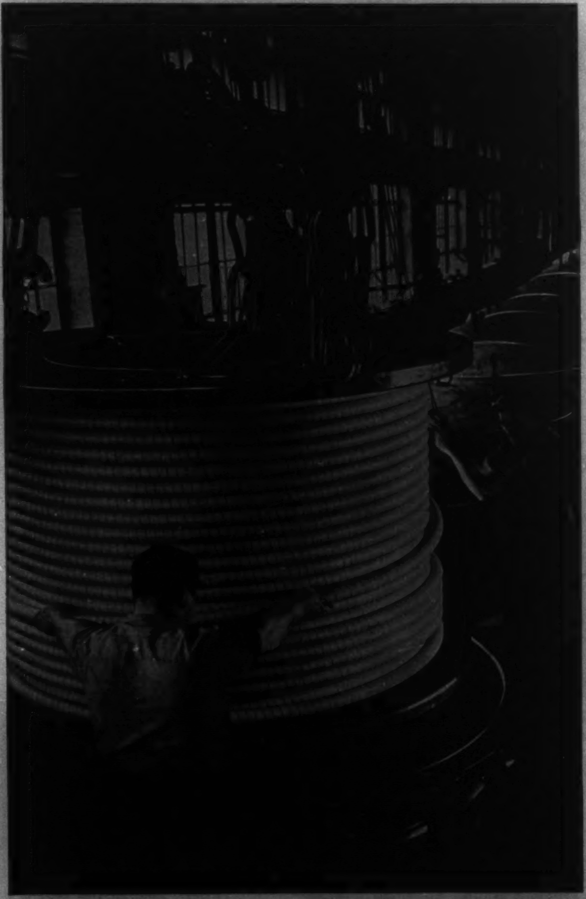

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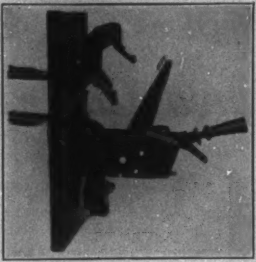

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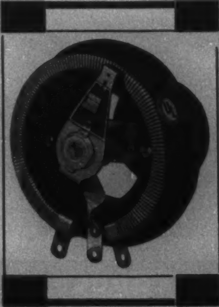

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The instrument requires no d-c path and is insensitive to direct current. If both d-c and a-c are present in a circuit, the voltmeter selects only the a-c with no appreciable frequency error.

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(Figures in Parentheses Give Dates of Latest Editions)

No.	Title	Price
No. 1	General Principles Upon Which Temperature Limits Are Based in the Rating of Electrical Machinery (4-25)	$0.20
4	Measurement of Test Voltage in Dielectric Tests (5-28)	.30
*C50	Rotating Electrical Machinery, Supersedes Nos. 5, 7, 8, 9 and 10 (4-36)	1.30
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*16	Railway Control Apparatus (1-33)	.40
*17f	Mathematical Symbols (2-28)	.30
*17g1	Letter Symbols for Electrical Quantities (11-28)	.20
*17g2	Graphical Symbols for Electric Power and Wiring (1-34)	.20
*17g3	Graphical Symbols for Radio (1-34)	.20
*17g5	Graphical Symbols for Electric Traction Including Railway Signaling (1-34)	.40
*17g6	Graphical Symbols for Telephone and Telegraph Use (3-29)	.20
*18	Capacitors (6-34)	.20
19	Oil Circuit Breakers (7-25)	.30
20	Air Circuit Breakers (5-30)	.30
22	Disconnecting and Horn Gap Switches (7-25)	.30
26	Automatic Stations (5-30)	.30
27	Switchboards and Switching Equipment for Power and Light (10-30)	.30
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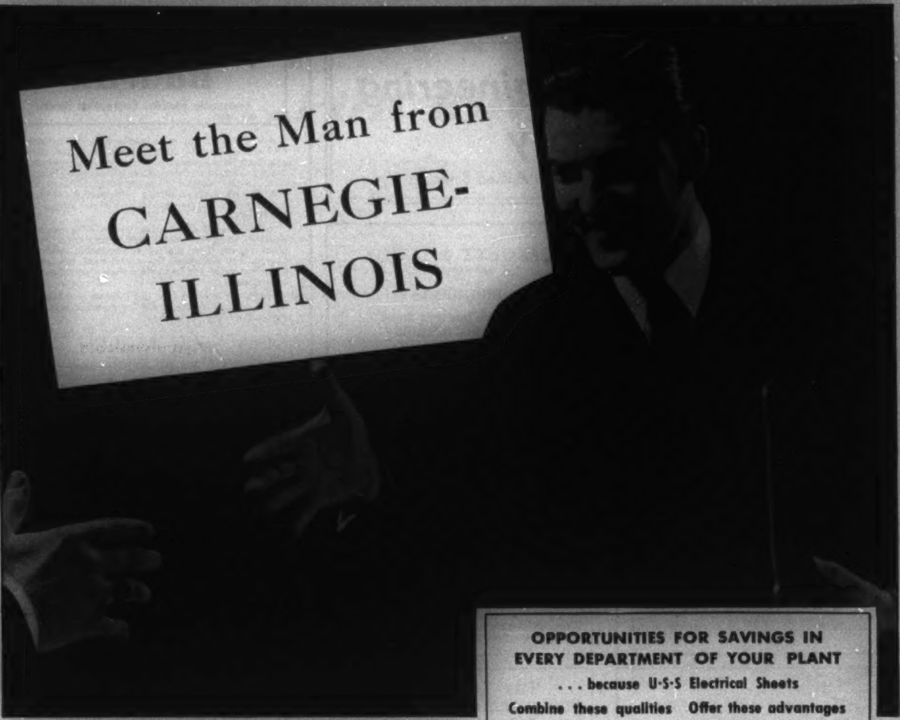

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E.E., B.S., J.H.U., '23, married, 37; 14 yrs mfg and util exper, including des and constr of overhead and underground systems. Available immed. Location, East. E-108.

ELECTRONIC ENGR, 10 yrs exper in phototube control, amplifier des, relay systems, grid-controlled rectifiers and mech des. Exper in patent procedure; 6 yrs chief engr [illegible] research lab. E-113.

GRAD E.E., 1929, married, 32; 8 yrs planning and des overhead and underground transm and distr systems; now employed; desires pos with util or mfr. Location immaterial. E-124.

E.E., 26, exper in efficiency engg, knowledge of elec rates; now employed as elec engr for a large nat corp. E-112.

E.E., grad from Minn, 1936, single 25. Desires pos in Middlewest. Draftg and shop exper in devpmt of elec controls for air conditioning, but desires more secure pos in devpmt field. E-109-8782-Chicago.

E.E., B.S., M.S., 1936, Univ Cal, single, 24, now employed. Desires pos with elec mfr, pub util. Interested high voltage. Exper: One yr indus elec maintenance, draftg, reports. Ambitious, responsible. E-110.

E.E., B.S., Poly Inst of Brooklyn, 1937, single, 22, H K N; desires a pos in elec field. Location immaterial, but prefers N Y and surrounding States. Available on notice. E-115.

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E.E., '35, Cornell, single 27. Over 2 yrs elevator and escalator exper; 6 mos heat pwr engg exper. Desires sales engrg or exec pos preferably in East. E-120.

E.E., B.S., 1937, Cooper Union, 21; highest marks in elec measuring, testg. Excellent draftsman. Desires pos with elec instrument mfg co. Location immaterial; willing work on trial, available immed. E-121.

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B.S., M.S. in E.E., MIT, '28, married, 33, G E test, 4 yrs exper on automatic switchgear, 6 yrs teaching exper, employed, desires advancement. E-119.

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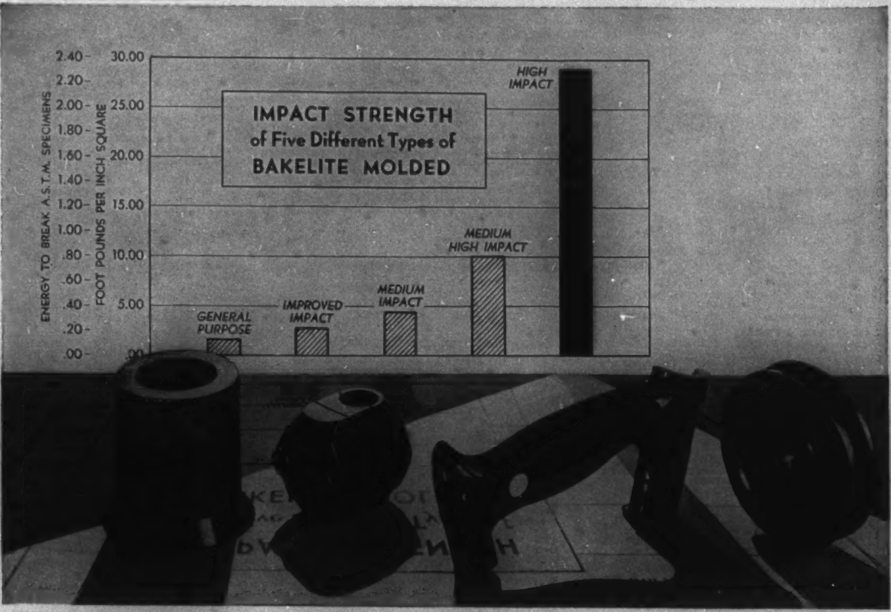

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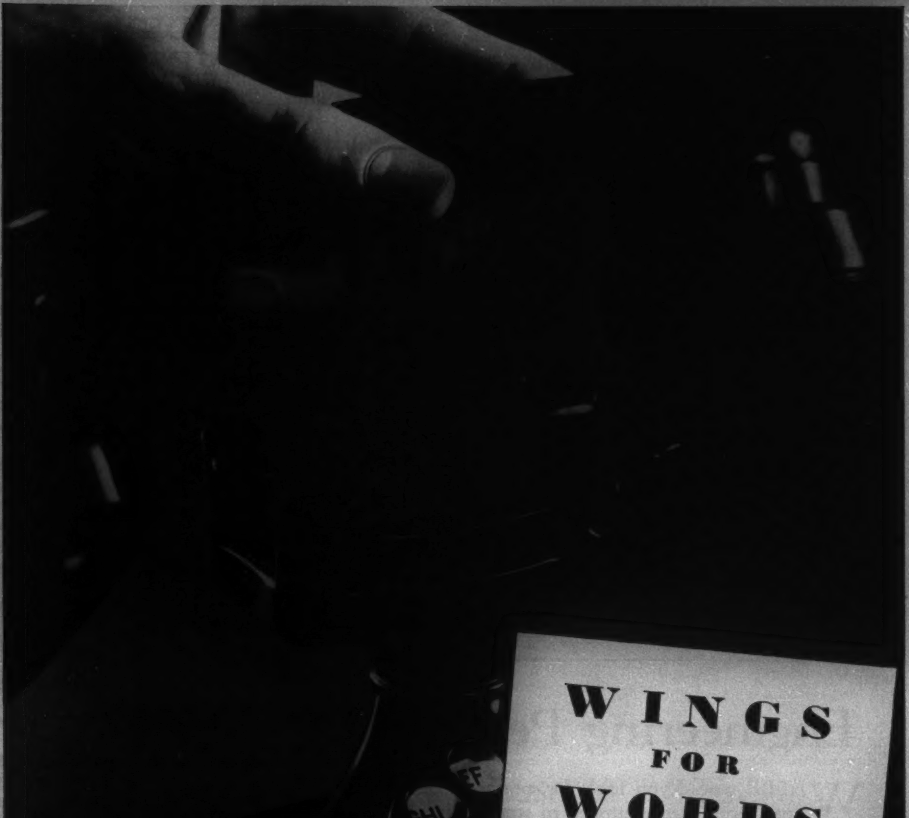

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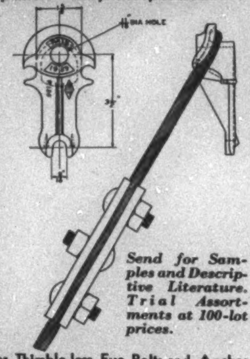

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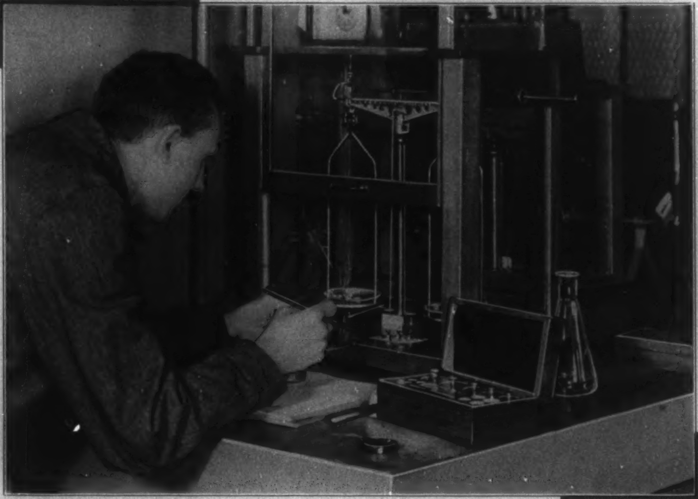

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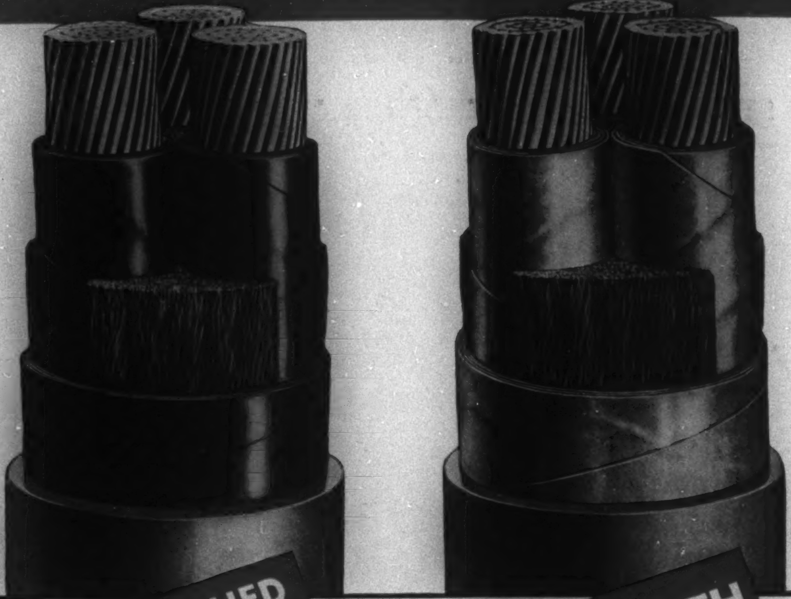

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